Master Vellum

FINAL TECHNICAL REPORT

NONDISSIPATIVE DC to DC REGULATOR-CONVERTER STUDY

15 JUNE 1964 TO 31 MARCH 1967

Contract No.: NAS 5-3921

Prepared by

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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GREENBELT, MARYLAND

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1.0 ABSTRACT

This report covers the entire work effort done on this program from 15 June 1964 to 31 March 1967. This effort was principally a research, design and development program providing modularization concepts, techniques, and circuitry for nondissipative regulator converters.

A variable frequency self-stabilizing chopper circuit was investigated during the first phase of this program. Although successful open loop control of this circuit was obtained on several breadboards, it was recommended that further development of this circuit be discontinued because of the undue control circuit complexity required to satisfy the electrical requirements, and consequently the failure of this circuit to achieve the modularization goals. Development of these breadboards was conducted only to the extent of obtaining satisfactory static open loop performance; no investigations were conducted with this circuit into the areas of circuit protection or dynamic response.

A fixed frequency self-stabilizing booster circuit was also investigated during the first phase of this program, and successful open loop control of this circuit was obtained with several breadboards. Development effort during this phase was limited to static open loop performance only. It was recommended, at the completion of the Phase I program, that further development effort be conducted with this circuit to obtain satisfactory closed loop performance. At this time, the following problem areas were known and recognized: Input current ripple, output voltage ripple, and circuit protection. Any potential problem areas with closed loop static regulation or dynamic response were unpredictable at this time.

Successful solutions to the input/output ripple problems were obtained by selection and application of appropriate passive filter circuit configurations; this effort was covered in detail in the sixth quarterly report. A solution to the circuit protection problem was achieved during the sixth quarter's effort. However, this solution provided circuit protection for short circuit load conditions only. In subsequent reviews with the NASA technical representatives, it was determined that overload protection, in addition to short circuit protection, would be highly desirable at the lower power levels (10 and 25 watts). A successful solution to this problem was obtained during the seventh quarter's effort.

Effort toward obtaining closed loop control of the booster converters was initiated during the sixth quarter. The initial test results by the end of that quarter indicated that the static regulation requirement of ± 1% could be obtained with the control and regulator circuits tentatively selected. Consistent with the

program plan, no detailed passive and active component tolerance effects or dynamic response data had been covered in any detail by the completion of this quarterly period.

The component tolerance investigations conducted during the seventh quarter pointed out several deficiencies in the voltage regulator circuit that had been tentatively selected in the previous quarter. The results of these investigations showed that additional amplifiers would be required to insure that the static regulation requirement could be obtained under all load, line and ambient conditions. However, the use of these additional circuits caused severe stability problems. The stability problems were solved by the use of several compensating circuits within the voltage regulator.

Dynamic response investigations were conducted at the same time as the component tolerance investigations. An empirical approach rather than a formal analytical approach was applied in this effort because of the funding limitations of the program. The initial results of these investigations definitely showed that the desired dynamic response, particularly that of dynamic voltage regulation (± 2% peak voltage), could not be met with the high gain voltage regulators with multiple compensating circuits. Additional dynamic response testing with the original voltage regulator circuit selected showed that the dynamic response design goals could be met over a large portion of the input voltage range. The above results were reported in the seventh quarterly report. It was decided that the original voltage regulator circuit investigated be used with special consideration given to minimizing the component tolerance effects.

The interfacing of the closed loop control booster converters and the converter protection circuits resulted in the problem of output voltage sensing. Solutions to this problem were satisfactorily obtained and the results reported in the seventh quarterly report.

It was recommended at the end of the Phase I effort that a new series of chopper regulator converters be investigated using the control concepts successfully obtained with the booster regulator converters. In addition, a unified power stage concept was presented which indicated that identical power components could be used in either a chopper or booster configuration with proper consideration given to the direction of power flow. Indications were also evident that the same control and regulator circuits could be used in either a chopper or booster configuration with appropriate changes being made to accommodate the different operating voltage levels. This effort was initiated in the seventh quarter.

A severe design problem was uncovered when attempting to operate over the entire input voltage range. The detail factors contributing to this problem were the set-reset limitations of the driver transformer, the reverse bias emitter base voltage rating of the main chopper transistor and the minimum required reset time of the basic frequency source. In a subsequent review of this problem with the NASA technical representatives, it was agreed that operation of the new choppers over a limited input voltage range would be acceptable. This modification eliminated the problem area. Although the main chopper transistor is now operating at the limit of its emitter base voltage ratings, reliability considerations still point to this item as a problem area. No detail effort was expended to obtain closed loop performance, obtain satisfactory circuit protection, or dynamic response.

2.0 PURPOSE

The purpose of this program was to provide concepts, techniques, and developed modular circuitry for non-dissipative DC to DC converters in the power range of up to 100 watts.

Major program goals were the maximization of efficiency, simplicity, and reliability, along with the minimization of size, weight, and response times of the converters.

The circuits were to be modular in concept, so that a minimum of development would be required to tailor a circuit to a specific application requirement. The concept was to also allow, inasmuch as practical, for the use of state-of-the-art manufacturing techniques.

The program was multi-phased, including a study, analysis, and design phase, and a breadboard phase during which the concepts were to be verified by construction and test of eight breadboards in the Phase I program, and 8 additional breadboards in the Phase II program.

3.0 INTRODUCTION

This report covers the entire work effort done on this program from 15 June 1964 to 31 March 1967. This effort was principally a research, design, and development program providing modularization concepts, techniques and circuitry for nondissipative regulator converters. The regulator converters studied in this program were to be capable of providing voltage regulation under variable conditions of line, load, and environment. Considerations were to be given to: Reliability, efficiency, weight, size, input and output ripple, dynamic regulation, and recovery time. The electrical characteristics of the regulator converters is given in Table I.

The program was divided into two major phases. The effort in Phase I was principally concerned with the power stage circuitry. The effort in Phase II was principally concerned with obtaining closed loop control, input and output ripple filtering, and circuit protection.

Phase I Effort

An initial search and analysis phase was conducted. Included in this effort was a literature search, an analysis of voltage control techniques, a study of efficiency versus switching frequency and a component materials review.

Development effort was first initiated on the chopper series of regulator converters. The self-stabilizing chopper was selected as the basic power stage. Several problem areas with the self-stabilizing scheme were uncovered early in the breadboard development phase which required extensive investigations. The problems were associated with circuit starting, circuit recovery time, and balanced operation. Solutions of each of these problems were determined. A nominal switching frequency was selected based on frequency-efficiency testing and a preliminary size and weight analysis of the 10 watt chopper.

Initial development effort on the chopper circuit was done at the 10 watt level. Scaling designs for the 25, 50 and 100 watt power levels were based on the results of the 10 watt development program.

Development effort on the booster series of regulator-converters was initiated near the completion of development effort on the chopper power supplies. The results of the frequency-efficiency testing were utilized in the selection of the nominal switching frequency for the booster. A "flyback booster" using a line compensated pulse width modulator was selected for the basic power stage. Minor development problems occurred, such as selection of choke inductance for proper no load and full load operation, limiting the flyback transistor peak current and control circuit compensation. Solutions to these problems were determined.

Initial development effort on the booster circuit was done at the 10 watt level. Scaling designs for the 25, 50, and 100 watt power levels were based on the results of the 10 watt program.

Selected electrical performance tests were run on the four chopper breadboards and four booster breadboards. These breadboards were open-loop configurations and were manually controlled. Data analysis was performed on each of the 10 watt power supplies.

Phase II Effort

Continuing development effort was made on the booster regulator converters previously investigated in the Phase I effort. Areas covered in Phase II included control circuits, protection circuits, input and output filter circuits, closed loop control operation, dynamic regulation and recovery time. Selected performance tests were run on four booster breadboards of power levels of 10, 25, 50, and 100 watts. These breadboards were complete closed loop controlled configurations.

New development effort was started on a chopper regulator converter having the same control circuits previously developed for the booster regulator converters. Initial development on the new chopper circuit was done at the 10 watt level. Scaling designs for the 25, 50, and 100 watt power levels were based on the results of the 10 watt program. Selected electrical performance tests were run on the four chopper breadboards. These breadboards were open loop configurations and were manually controlled.

TABLE I

ELECTRICAL CHARACTERISTICS OF PRE-REGULATOR CONVERTERS

Reg. - Conv. Configuration	Voltage Input, V	Voltage Output V	Power Watts	V out Ripple MV P-P	I in Ripple MA PK	Size Cu. In.	Weight Oz.
A	10-20	22	10	20	15	15	10
B	10-20	9	10	20	25	15	10
C	10-20	22	25	40	30	20	12
D	10-20	9	25	40	50	20	12
E	12-20	22	50	60	60	25	14
F	12-20	11	50	60	100	25	14
G	22-33	35	100	75	120	30	16
H	22-33	21	100	80	200	30	16

All:

Regulation: ± 1% for Line and 75-100% or 100-75% Load
Recovery Time: 50 m sec. maximum (10 milliseconds objective)
Transient Excursion: ± 2% maximum
Efficiency: 90% minimum with output powers above 25%
Temperature: -20 to +70°C

4.0 TECHNICAL DISCUSSION

4.1 Initial Search and Analysis

4.1.1 Literature Search

The literature search revealed only five basic, non-dissipative switching type regulator-converters. They are:

a. Chopper Regulator
b. Capacitive Divider
c. Bedford Step-up
d. Capacitive Doubler
e. Inverter-Rectifier

The first two are "buck" systems, the second two are "boost" systems, and the last may be either.

Of these five basic types, a number of variations exist. The most obvious variation is the push-pull connection. In general, the other variations differ only in drive circuitry and the means of controlling the output duty cycle. The only known exception to this statement is the use of the "positive clamp" which changes the inverter-rectifier to the booster and hence modifies the circuit function.

There are also many other variations which use a combination of basic circuits. An example is the use of a chopper regulator to supply an unregulated inverter-rectifier and in this manner maintain a regulated output voltage. In general, these variations are more complex and inherently less efficient than the basic types and so are not considered here.

Circuitry Selection Criteria

A group of factors to be used as criteria for selection of circuitry were jointly agreed upon by NASA and HSED Engineering. The factors selected for evaluation were:

1. Degree of commanality of circuitry for "buck" or "boost".
2. Number of magnetic components
3. Number of components

4. Efficiency
5. Input ripple current
6. Output ripple voltage
7. Overload/short circuit protection
8. Minimum size and weight
9. Isolation of input/output grounds

Two additional criteria, that of output voltage regulation and dynamic regulation recovery time, initially appeared in the above list, but have been deleted on the basis that these items are determined by the control circuitry rather than the basic power stage.

Comparison of Power Stages

Figure 1 shows eight power stages, which represent the simplest configuration capable of performing the necessary functions.

In comparing these circuits, the assumptions were made that the power stages were independent of drive and control circuitry, and that all circuits were operated at the same repetition rate. This meant that the ripple components of the push-pull stages were at twice the frequency of those of the single ended stages and consequently easier to filter. Using the circuitry selection criteria as a basis for comparison, the circuits which were selected for further consideration were the single ended and push-pull chopper, the single ended and push-pull inverter-rectifiers, and the Bedford step-up converter.

Voltage Control Techniques

The voltage control techniques investigated for the regulator-converters were pulse-width, pulse, ratio, and pulse-frequency modulation.

Sorenson [1)] presents a very descriptive discussion of the various means of modulation, using switching techniques, in which he discusses the characteristics of pulse-width, pulse ratio, and two types of pulse-frequency modulation.

Several points can be taken from his discussion:

a. Some controllers inherently have minimum ON or OFF times.
b. In modulation systems in which the frequency varies, the output low-pass filter must be designed for the lowest frequency.

1) "Linear Control using On-Off Controllers" A Sorenson, Electro-Technology V17, v4, April 1963.

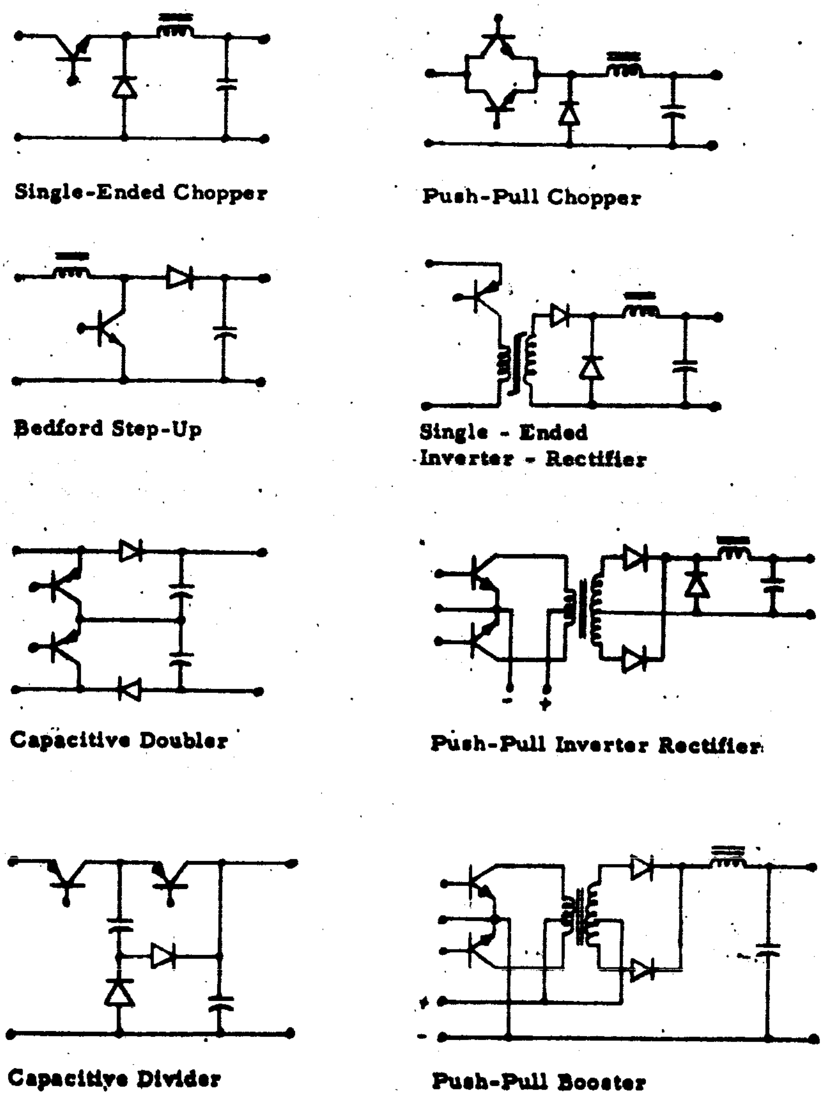


FIGURE 1

REPRESENTATIVE BASIC POWER STAGES

c. If either the ON of OFF time approaches zero, the bandwidth of the controller must approach infinity.

The first point may be seen in, for example, the monostable multivibrator, which has a minimum recovery, or OFF, time. The second point, obviously, implies that the filter for a given regulator will be smallest for a pulse-width modulated system, since its frequency is fixed. The third point has several implications. First the design of the controller is more severe. Second, since the gain bandwidth product of any physically realizable controller is limited, this means that the regulation of the device suffers because of decreasing gain, and the controller may tend to be unstable.

Assuming no transformer scaling, regulator B must produce 9 volts from a 10-20 volt source. Allowing for a 1 volt series drop, the duty ratio must vary from 100% down to about 45%. Likewise, regulator G must produce 35 volts from a 22-23 volt source, with a duty ratio varying from about 40% to 5%. If transformer scaling is used, the turns ratio may be adjusted for, say, a set-up of 1.15, which shifts the duty ratio of regulator B to a range of 87% to 39%, thus decreasing the severity of the bandwidth requirement.

Another means of bypassing points a) and c) above is through the use of two modulating functions simultaneously, as in either the Pulse Width Modulated Power Supply or the Self-Stabilizing Chopper. Here a constant volt-second transformer establishes the ON time and varies the duty ratio as a function of input voltage, while a separate bistable multivibrator, operating over a relatively narrow range of frequencies, furnishes the necessary OFF time to compensate for load changes. In the limiting case of near 100% duty cycle, the transformer is operating close to its normal 180° saturated switching mode, and the multivibrator is operating close to its design frequency.

It should be noted that since the low-pass output filters are LC with free-wheeling diodes, it is advantageous, from an efficiency viewpoint, to limit the OFF time as much as possible and hence decrease the amount of conduction time of the diode.

Efficiency Versus Switching Frequency

Investigations were conducted into the loss of characteristics of semiconductors and transformers in an effort to determine the maximum switching frequency consistent with high efficiency and minimum size and weight .

Frequency Range Characteristics of Semiconductors

In order to determine the usable frequency range as a function of the semiconductor characteristics, a model was established, consisting of a single transistor switching through an ideal choke input filter into a resistive load with voltages, currents, and duty cycle equivalent to those of the 10 watt regulator. Efficiency calculations were made for the model. In the calculations, delay and storage times were not considered. Transistor OFF losses were also ignored as being only a small percentage of total losses. Calculations were made at frequencies of 1, 10, 100, 250, and 500 KC with the 2N2880 and 2N1908X transistors operating with duty cycles of 45% and 90%. The results of these calculations were as follows:

In the very low frequencies, switching time was insignificant, and the 2N1908X was superior because of its lower saturation voltage. The condition of 45% duty cycle was more efficient than the 90% condition merely because the ON losses occurred for a smaller portion of the period.

In the higher frequencies, where switching time was a significant portion of the period, the 2N2880 was clearly superior by virtue of its switching speed. The 2N1908X cannot be operated much above 100 KC, because of the assumed switching speed, since above this frequency the switching time soon became greater than the ON time. In the higher frequency region, the 90% duty cycle condition was the most efficient because the ratio of switching time/ON was less than that for the 45% condition.

Frequency Range Characteristics of Transformers

Several sample designs were done for the 10-watt output transformer. The designs were based on the use of Indiana General type 0-5 material, a low loss ferrite, and the results showed that relatively efficient transformers with reasonable sizes and weights can be designed for operation to at least 50 KC. What was not apparent from the results was a definitive relationship among efficiency, weight, and frequency of operation. General Electric confronted with the same problem developed an analysis to determine a definitive relationship of efficiency, weight, and size versus frequency of operation [2)]

2) Voltage Regulation and Conversion in Unconventional Electrical Generator Systems, Final Report, Volume 2, August 31, 1963, Bureau of Naval Weapons Contract NOW 62-0984-d.

The analysis showed that core and winding losses varied as the cube of transformer dimensions while power rating varied as the fourth power of transformer dimensions. Therefore, an increase in the size of a transformer, with all other quantities held constant, increased the efficiency of operation.

Efficiency was also effected by the current density. Winding losses increased as the square of current density while output power was directly proportional to this same parameter. Therefore, efficiency was ultimately adversely affected. However, up to the point at which core and winding losses were equal, increasing current density improved efficiency. In practice, even further increases were desirable to improve light load operation and to attain a greater power output for a given design weight.

An analysis comparing power loss and transformer weight for two different core materials was performed for a 100 watt design. By scaling, the results of this analysis were extended to apply to different power levels. The main result of this analysis indicated the possibility of efficient transformer designs at reasonable weights throughout the 10 KCPS to 100 KCPS frequency range.

Materials Review

A review of electrical components was made to determine component availability and component limitations for high frequency switching.

Semiconductors

Vendor literature was searched for transistors with fast switching times and low saturation voltages. Lists were compiled of the available transistors and high-speed power rectifiers within the applicable power, voltage, and current range.

In the lower power range numerous transistors and diodes with high frequency capabilities were available.

Magnetic Materials

One of the considerations of this program was to minimize the contribution of the magnetic components to stray magnetic fields. Several factors which contributed to stray fields were air-gaps, non-uniform winding distributions, and loose coupling between windings and core.

In surveying the available magnetic materials, both stamped laminations and c-cores were eliminated immediately because they have built-in air-gaps and because their windings cannot be uniformly distributed or tightly-coupled to the core. The hermetically-sealed, oil-filled, tape wound variety of toroids was considered, but these cores were operable up to about 10 K CPS, beyond which the core losses became prohibitive.

The configurations which offered the most promise were the toroidal and the tape-wound bobbin cores. The toroids offered high permeability, uniform winding distribution, tight coupling, and inductive tolerances of about ± 20% maximum. The tape-wound bobbin cores covered the frequency range of 2 K CPS to 500 K CPS. These tape-wound cores were available in either Orthonol or Permalloy 80 materials.

In the power-frequency range, say up to 500 cps, the prime requisite for core material was high permeability, and core losses and switching time were secondary considerations. In the audio range, from 500 cps to 15 K CPS, both hysteresis and eddy current losses became important, and only moderate permeability was required. In the high frequency range, from 15 KCPS upward, eddy current losses predominated, switching time became important and permeability was quite low.

At this time, little specific information regarding the magnitude of losses, versus frequency, had been assembled. However, the following table shows, for each frequency range, the relative characteristics of the applicable core materials:

TABLE II RELATIVE CHARACTERISTICS OF CORE MATERIALS FOR SPECIFIC FREQUENCY RANGES.

Freq. CPS	Core Material	Hysteresis Loss	Eddy Cur. Loss	Permeability
0.5-15KC	Moly-Perm Powder	Low	Low	High, Decreasing
	Iron Powder	Moderate	Low	High, Decreasing
	Ferrite	High	Low	Low, Constant

TABLE II (Continued)

Freq. CPS	Core Material	Hysteresis Loss	Eddy Cur. Loss	Permeability
15-40KC	Moly-Perm. Powder	Low	High	Moderate, Decreasing
	Iron Powder	Low	Moderate	Moderate, Decreasing.
	Ferrite	Moderate	Low	Moderate, Constant
40-200 KC	Moly-Perm. Powder	Low	Excessive	Low
	Iron Powder	Low	High	Low
	Ferrite	Low	Low	High

(Tape-wound bobbin cores not included because loss curves are not available).

4.2 Development of a Chopper Regulator - Phase I Program

Initial investigations into the development of a chopper regulator resulted in the selection of the pulse width and frequency modulated self-stabilizing chopper for further development. The basic self-stabilizing chopper power stage shown in Figure 2 consists of two push-pull power transistors Q1 and Q2, two driver transistors Q3 and Q4, and a saturating core drive transformer T1. The use of a saturating core drive transformer results in inherent regulation of the output voltage with variations in input line voltage. However, the self-stabilizing chopper coes not have inherent regulation for variations in load, and regulation for load variations is provided by a variable drive frequency to the chopper stage.

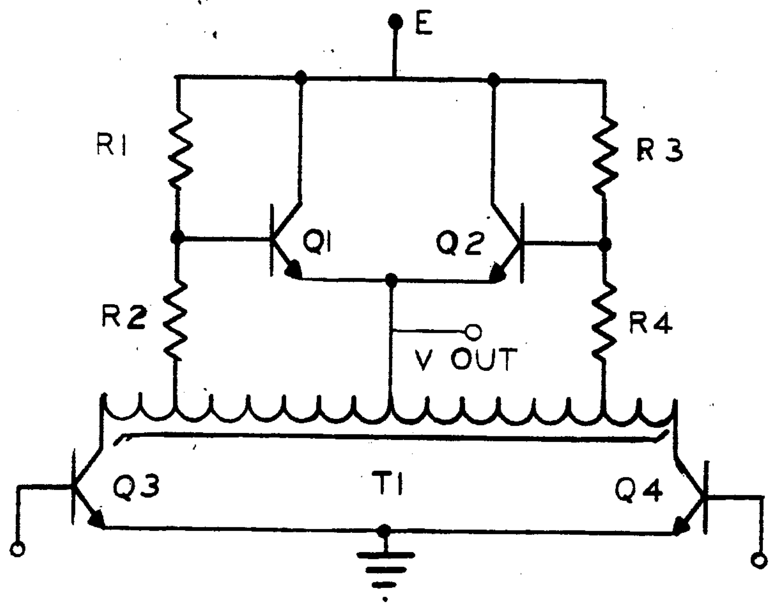


FIGURE 2 BASIC PUSH-PULL SELF-STABILIZING CHOPPER POWER STAGE

Several problem areas were uncovered with the basic self-stabilizing chopper scheme early in the breadboard development stage. One problem was concerned with circuit starting. A second problem was associated with insuring rapid turn-off of the self-stabilizing chopper after the drive transformer T1 saturated. A third problem was associated with obtaining a balanced output of the push-pull stage consisting of transistors Q1 and Q2.

The solutions to the first two problems consisted of the following circuit modifications. To remedy the starting problem, a gate pulse input was applied to the bases of transistors Q1 and Q2. This external means of starting the self-stabilizing chopper initiates each half cycle of operation. Rapid turn-off of the self-stabilizing chopper after the drive transformer T1 saturates was assisted by the introduction of degenerative feedback current limiting with the addition of an emitter resistor for transistors Q3 and Q4.

Two solutions to the balanced output problem were investigated. One solution was to increase the values of resistors R2 and R4 of Figure 2 to a value significantly larger than the maximum reflected input impedance characteristics of the chopper transistors. Unfortunately, this resulted in significant power losses in these resistors. An alternate solution was to require matched input impedances for the chopper transistors; this required both matching of transistor gain and base-emitter voltage. In addition, the input characteristics of the transistors also had to be closely matched for all possible voltage and load conditions.

The resultant disadvantages of the above solutions required an investigation for an alternate self-stabilizing scheme. The circuit concept investigated and accepted was a single-ended version of the basic push-pull chopper. The single-ended self-stabilizing chopper power stage is shown in Figure 3. Circuit operation is similar to the push-pull chopper except for the half wave rectification of the driver output by diodes D2 and D3, and the subsequent connection at the base of transistor Q1 in a frequency doubling configuration. Transistor Q1 then operates at twice the fundamental frequency of the system.

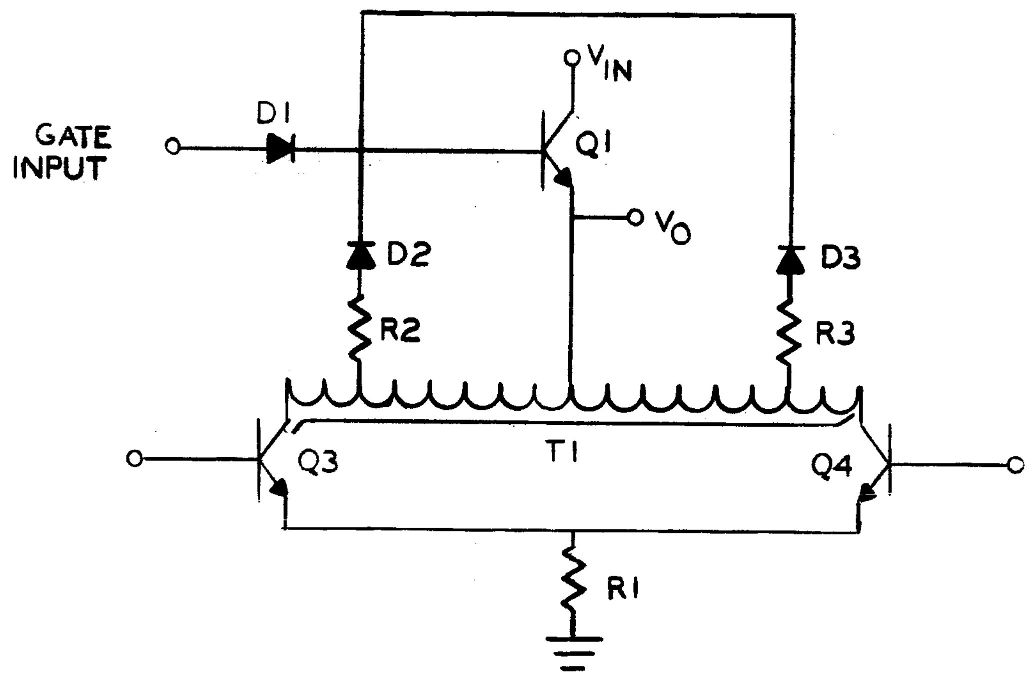


FIGURE 3 SINGLE ENDED SELF-STABILIZING CHOPPER POWER STAGE

The Phase I final circuit configuration of the chopper power supply is shown in Figure 4. Since the chopper is working in the open loop configuration, a separate voltage source is required for the variable frequency oscillator and drive circuitry. The chopper power supply consists of an oscillator, a driver stage, a gate circuit, a power stage and an output filter.

The oscillator is a conventional saturating core square wave oscillator consisting of a push-pull amplifier, transistors Q1 and Q2, a saturating transformer T1, which supplies base drive to the transistors and an output

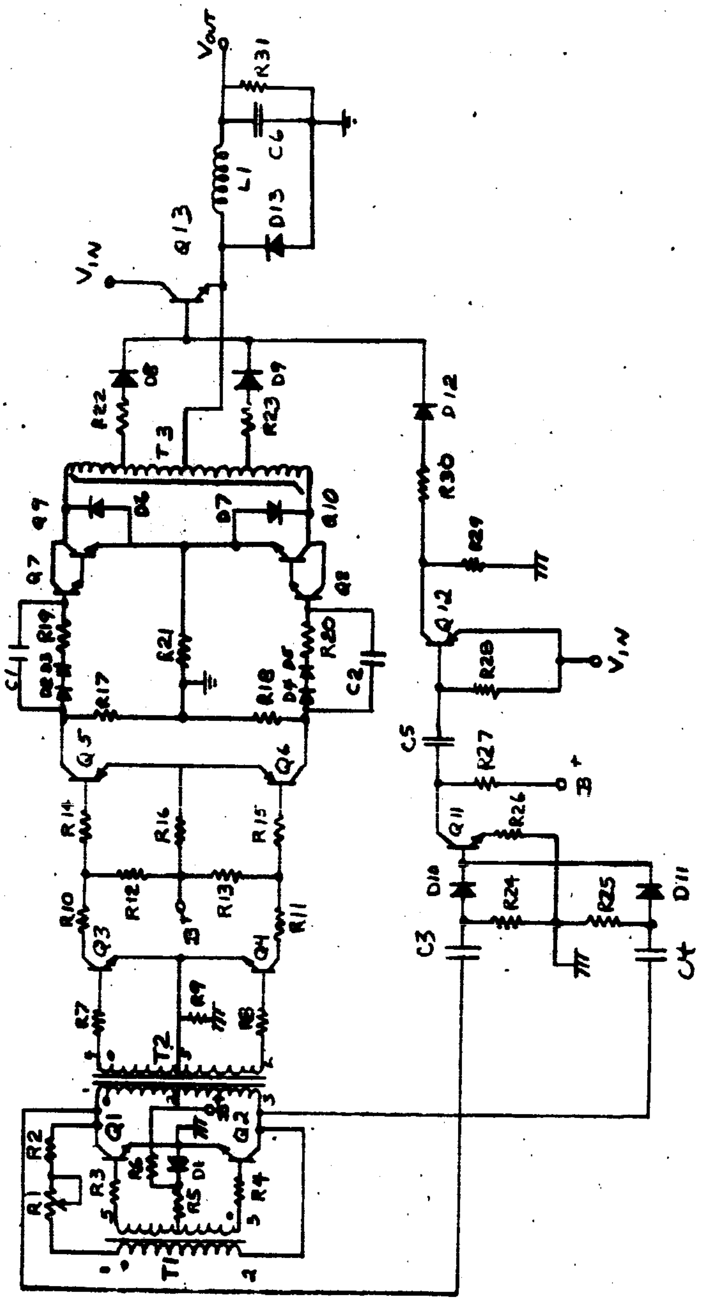


FIGURE 4
FINAL CIRCUIT CONFIGURATION
CHOPPER REGULATOR

coupling transformer T2. A starting circuit of diode D1 and resistor R6 insures starting of the oscillator.

The gate circuit consists of a set of pulse amplifiers, the operation of which is described as follows: The square wave across transformer T2 is differentiated by R24-C3 and R25-C4, half-wave rectified and applied to the base of transistor Q11 as a train of positive pulses at twice the frequency of the oscillator. Two transistor stages are required to provide adequate amplification of the pulses to the base of transistor Q13. This is accomplished mainly by the second stage, transistor Q12, whose B+ is made to follow the input to chopper transistor Q13.

The driver stage consists of two push-pull stages (Q3-Q6) and a push-pull Darlington pair (Q7-Q10) for driving the main chopper transistor. The use of Darlington amplifiers in the third stage is necessary to achieve the high gain requirements.

The output filter consists of a free-wheeling diode D13 and a low pass filter consisting of choke L1 and capacitor C6.

The operation of the chopper system is as follows: Assume a positive voltage is applied to the base of drive transistor Q7. At the same instant, a positive pulse from the gate circuit is applied to the base of chopper transistor Q13. This turns transistor Q13 on for a very short instant of time. Through transformer action, base drive for transistor Q13 begins to flow. When the volt-second product of transformer T3 is exceeded, T3 saturates and current limiting results. The base drive to transistor Q13 collapses and Q13 turns off. The other half-cycle is initiated when the base of transistor Q8 is forward biased at the same instant transistor Q13 is pulsed on. Regeneration occurs and the process repeats itself.

Self-stabilization of the chopper is obtained through the constant volt-second product of the saturating core drive transformer T1. The volt-second product of this transformer is capable of sustaining a voltage of E volts for a time of t seconds. Thus, at a fixed load and frequency, the on time of the core will decrease in proportion to the increase in voltage to maintain the constant volt-second product. This results in inherent regulation of the output voltage with variations of input line voltage.

The output voltage from the chopper is applied across the free wheeling diode D13. The low pass filter averages this chopped voltage to provide the desired DC output voltage.

Successful open loop control of this circuit was obtained on several breadboards at power levels of 10, 25, 50, and 100 watts. However, the tests showed that several major impediments existed with this circuit. The degenerative feedback method of current limiting was shown to be the most effective method of improving circuit recovery, but this method of current limiting required a significantly larger range of operating frequency to maintain output voltage control. In addition, the voltage regulation tests showed that all power supplies had poor inherent regulation as a result of this method of current limiting. The ability to obtain modularization with this power stage concept appeared to be severely hampered by the current limiting requirement.

For these reasons, it was recommended that further development effort on the above chopper concept be discontinued.

4.3 Development of a Booster Regulator - Phase I

Initial investigations into the development of a booster series of power supplies resulted in the selection of the push-pull inverter-rectifier as the basic booster power stage. Subsequent preliminary tests on the chopper series of power supplies indicated that the weight and efficiency goals would probably be impossible to meet with the inverter-rectifier circuit. A re-evaluation of the available booster power stages was conducted, resulting in the selection of the basic flyback converter as the booster power stage.

The basic flyback circuit shown in Figure 5 makes use of an induced voltage in series with the source voltage to boost the output voltage.

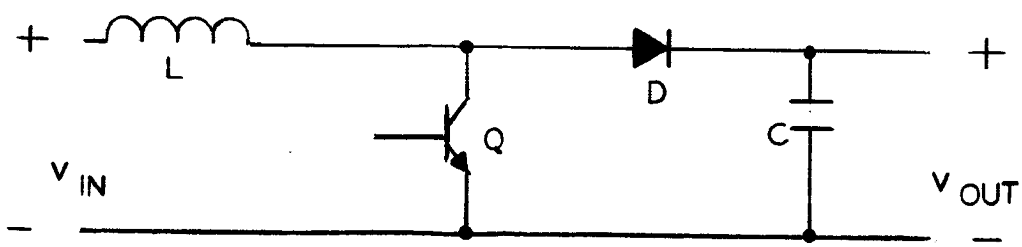


FIGURE 5 BASIC FLYBACK BOOSTER CIRCUIT

Transistor Q is switched on and off by the control circuit, and diode D is switched by the changing bias voltage caused by the switching of transistor Q. With transistor Q on and diode D off, the voltage across the inductor L is equal to V in, and there is a linear current build-up in L. After a given time, transistor Q is turned off and diode D is forward biased.

The current through the inductor L is then directed through diode D, capa citor C and the load. The voltage induced in the inductor L is thus added to the input voltage thus producing an output voltage higher than the input voltage. During the next half cycle, transistor Q turns on and diode D becomes back biased so that inductor L is storing energy and capacitor C is discharging its energy into the load.

The output voltage of the flyback booster can theoretically be boosted to any voltage greater than the input. The maximum boost voltage is limited by the switching characteristics of the flyback transistor, diode, and the energy storage capabilities of the inductor and capacitor.

Several minor development problems occurred during the initial development phase for the booster. One problem was concerned with the selection of choke inductance for proper no load and full load operation. A second problem was concerned with limiting the flyback transistor peak current. A third problem was concerned with line compensation of the booster.

The solution to the first problem was as follows: The inductor L was required to supply current for the load, the output capacitor and the control circuits while the booster transistor was off, and the current through the inductor decreased linearly during this part of the cycle. At extremely light loads, the DC current through the inductor approached zero before the end of the off time period of the booster transistor. The voltage across the inductor decreased when this occurred. This made the normal voltage compensation ineffective which resulted in an increase in the output voltage. To prevent this, a critical inductance was required and a bleeder load was used to maintain a minimum current for critical inductance.

The cause for the second problem was that the output of the converter was momentarily placed across the flyback transistor at the instant of transistor turn-on. This was caused by the finite recovery time of diode D in the flyback circuit. As a result of this, the transistor drew a spike of current much greater than the normal peak switching current. To solve this problem a fast switching rectifier was used for diode D, thus minimizing this spike current.

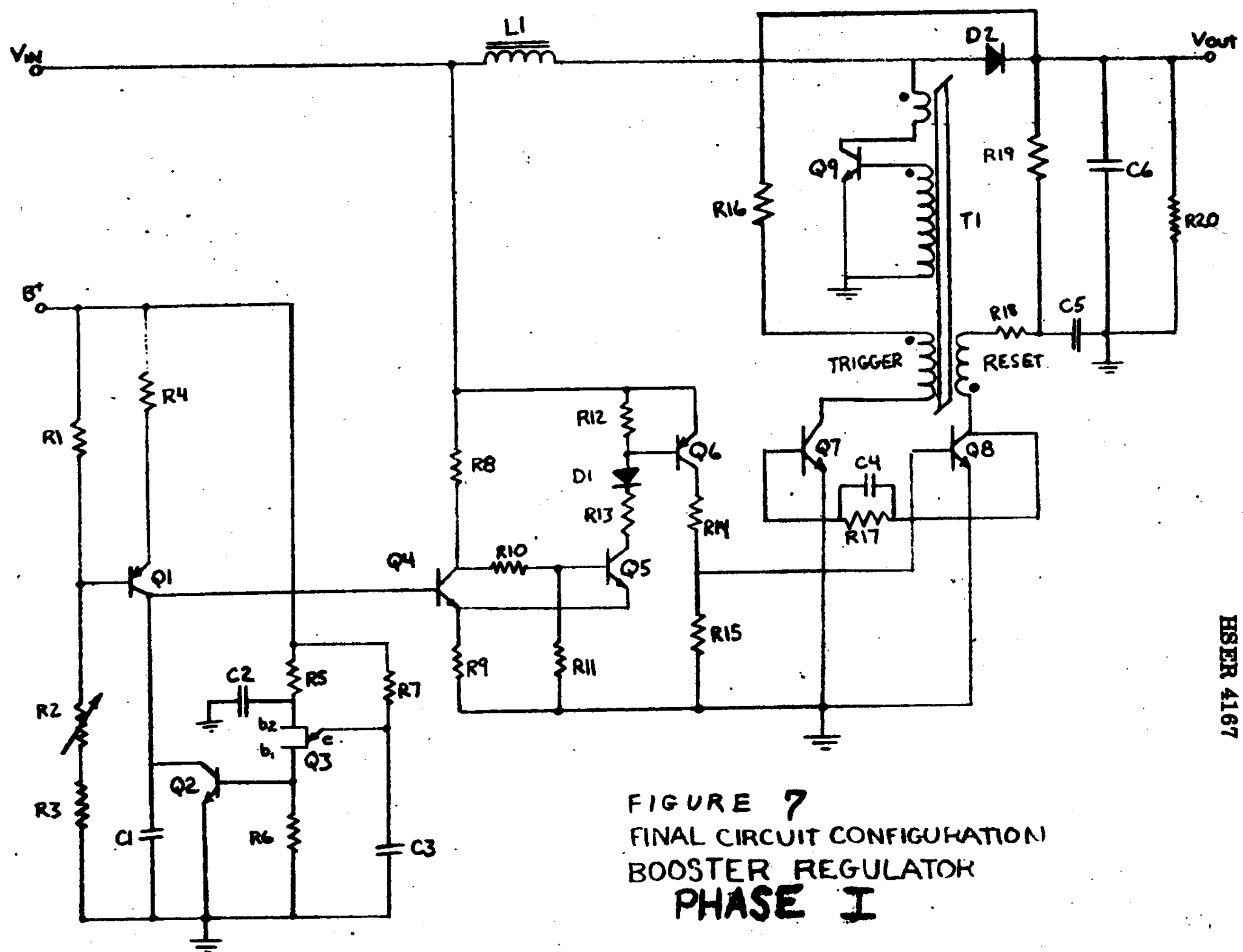


FIGURE 7
FINAL CIRCUIT CONFIGURATION
BOOSTER REGULATOR
PHASE I

The unijunction relaxation oscillator operates at a frequency of about 30 KC. Transistor Q2 is pulsed from the oscillator, causing a sawtooth voltage waveform to be formed across capacitor C1. This sawtooth voltage is fed into the pulse width modulator, providing a pulse width modulated voltage to switch the reset transistor Q8 on and off. The trigger transistor Q7 is turned on through capacitor C4 when transistor Q8 turns off. The flyback transistor Q9 is driven from transformer T1 and switched by two supplementary windings on the transformer, the trigger and reset windings. A current feedback approach is used to drive transistor Q9 because it supplies efficient drive at all line and load conditions. The trigger winding initiates the turn-on of transistor Q9. After turn-on, the current feedback supplies sufficient drive to maintain saturation. The reset winding resets the core during the off time of the flyback transistor and supplies a large negative voltage spike to insure fast transistor turn-off.

Four booster breadboards were constructed in the open loop configuration for power levels of 10, 25, 50, and 100 watts. Selected performance tests run on each breadboard consisted of efficiency, output voltage regulation, output voltage stability, overload and short circuit characteristic, output voltage stability, overload and short circuit characteristic, output voltage ripple, and input current ripple to acceptable values. The results also showed that further effort was necessary to provide overload and short circuit protection.

For these reasons, it was recommended that the Phase I booster concept be further developed in the Phase II program. Specific recommendations for the Phase II program included optimization of output and input filters, development of overload and short circuit protection, and development of circuitry for closed loop operation.

4.4 Development of a Booster Regulator - Phase II

Development effort for the booster series of regulator-converters continued in the Phase II program. The main areas of development were concerned with the following:

1. Closed Loop Control
2. Optimization of output and input filters
3. Development of short circuit and overload protection.

Closed Loop Control of the Booster Regulator Converters

The selection of a control concept for the booster required the selection and interfacing of the following circuit functions:

1. Frequency source
2. Pulse width modulator
3. Voltage regulator

An investigation of the circuits capable of performing the above functions was conducted. A detailed analysis of these circuits resulted in the following limited selection.

Frequency Sources

The pulse width modulators under consideration required either square wave inputs or sawtooth inputs. For the pulse width modulators that required square wave inputs, the astable multivibrator and the transformer coupled square wave oscillator were possible frequency source choices. The astable multivibrator supplied a good rectangular wave, but careful matching of circuit components was necessary to prevent dissymmetry in each cycle. The transformer coupled square wave oscillator supplied a good rectangular output and was inherently symmetrical, but because it required at least one transformer, it was undesirable. For the pulse width modulators that required sawtooth inputs, the sawtooth was obtained by using an R-C charging circuit that was periodically reset by a pulse train. The unijunction relaxation oscillator was a simple device that produced a relatively constant frequency pulse train with respect to input voltage fluctuations. It required a small number of components and supplied an inherently symmetrical output, and was therefore a logical choice where a constant frequency pulse train was required.

Pulse Width Modulators

A magnetic amplifier driven by a square wave oscillator filled all the needs of a high frequency pulse width modulator, and was considered for the application. However, because of the drawbacks of using magnetic circuits for voltage control functions and the drawbacks of the square wave oscillators, this system was rejected.

The following three pulse width modulating systems made use of the unijunction oscillator frequency source. The first system consisted of a monostable multivibrator used in conjunction with a constant frequency pulse generator. This system was made practical by controlling the delay time of the unstable state by either of two methods: By controlling the resistance of the R-C timing circuit, or by using a common emitter resistor biased from the variable input.

The second system used a zero axis crossing device or a difference amplifier in conjunction with a sawtooth generator. Experience has shown, however, that the switching of these devices deteriorated beyond acceptable limits when an emitter resistor was used for inherent regulation.

The third system made use of a Schmitt trigger fired by a controlled charge rate sawtooth generator. This system functioned identically to the monostable multivibrator with a controlled R-C circuit and an emitter resistor. This system offered fast switching, inherent voltage regulation, and simple closed loop operation.

As a result of the control circuitry investigations, the control system chosen for use in the closed-loop boosters was the unijunction relaxation oscillator, controlled charge rate sawtooth former, and Schmitt trigger. This system was identical to the control system used in the open-loop series of boosters.

The final circuit necessary for closed-loop control was the voltage regulator stage. Two circuits were considered for this application, a difference amplifier and a reference amplifier. Initial testing showed that both regulators have similar temperature stability and dynamic response, and either regulator was capable of regulating within the specified limits. The reference amplifier was chosen as the voltage regulator stage of the booster because of its reduced component count compared with the difference amplifier.

Optimization of Output and Input Filters

Size and Weight Reduction of Flyback Chokes

Molybdenum permalloy powder toroidal cores were selected as the basic core material for the filter and flyback chokes because of their:

1. Gapless construction minimizes the effects of stray magnetic fields.

2. Magnetic stability under conditions of DC magnetization and temperature.
3. High effective permeability at the operating frequencies of interest.

The original flyback chokes used in the Phase I program breadboards were designed as constant inductance chokes by maintaining essentially a constant permeability under conditions of varying DC current. The inductance variation of these chokes varied an average of only 20% as the DC current was varied from its specified minimum to its specified maximum. The flyback chokes varied an average of only 20% as the DC current was varied from its specified minimum to its specified maximum. The flyback chokes were redesigned to operate as swinging chokes in an attempt to achieve size and weight savings. The swinging inductance effect was obtained by operating the chokes into DC saturation under varying DC current, thereby producing an effective permeability dependent upon the magnitude of the DC current.

Optimization of Output Filter

The results of the Phase I breadboard testing showed that the output capacitance of the booster converter would have to be increased to reduce the output ripple to desirable limits.

Alternate filter schemes were investigated that could be used as supplementary filters. A pi section filter was determined to be the most applicable filter section for this application, since for proper operation of the flyback booster it must operate into a capacitive input filter. The pi filter can be broken into two sections: An input filter capacitor followed by a low pass LC section. The input filter capacitor determines the output ripple of the flyback booster, and the low pass LC section is set to obtain the desired ripple attenuation from the flyback booster to the load.

The components considered for the output filter were etched foil tantalum capacitors for the capacitive components and molybdenum permalloy inductors for the inductive components. The etched foil capacitors were considered instead of the wet slug type tantalum capacitors used in the Phase I program, because these components offered higher effective capacitances at the switching frequency (30 KC) of the converter and higher ripple voltage capability.

Optimization of Input Filter

The results of breadboard testing in the Phase I program showed that supplementary filtering was required for the booster regulator converters to reduce the input current ripple to acceptable levels. Subsequent testing showed that the magnitude of the ripple current was dependent on the DC source characteristics. Several conferences were held between NASA and Hamilton Standard technical representatives in an effort to obtain a definition of a typical satellite DC power source.

Tests were run at NASA Goddard using the simulated satellite power source shown in Figure 8. The satellite power source consisted of a Goddard Space Flight Center (GSFC) designed 2-amp solar array simulator, shunted by a battery pack consisting of 13 Yardney type YS-11 silver cadmium-cells and a GSFC designed shunt regulator. Output impedance data was obtained for the following conditions under varying loads:

1. Solar array simulator/shunt regulator with fully charged batteries floating across the line.
2. Solar array simulator/shunt regulator only.
3. Fully charged battery only.
4. Battery only, but nearly completely discharged.

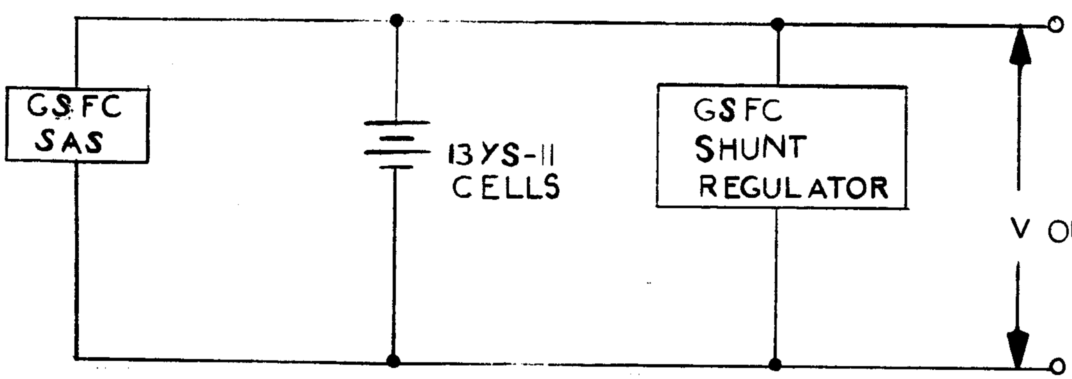


FIGURE 8 SIMULATED SATELLITE POWER SOURCE

The results of these tests are given in appendix I. Conditions 1 and 4 would be representative of actual conditions aboard a satellite. For condition 1 the DC voltage could be expected to be close to 20 volts DC; for condition 4, the DC voltage could be expected to be close to 12 volts DC.

Input filter configurations were defined for the 25 watt booster regulator. Input current ripple data was taken for conditions 1 and 4 above, and for an intermediate point (V_{IN} - 15 VDC) representing a battery charge condition. The results of these tests are shown in Table III.

Operating state condition II represented the input condition producing the highest input ripple current. This was to be expected since this condition represented low input voltage which corresponded to the maximum boost condition for the regulator converter. The asterisks indicated the first component condition, for a given filter configuration, that brought the input current ripple within spec limits.

The data indicated that either a capacitive input filter or a choke input filter could be utilized. The choke input filter configuration consisting of an inductance of 12 μh and capacitance of 82 μf represented the optimum filter configuration from the standpoint of minimum size and weight. The capacitive input filter was considered only where minimization of magnetics was absolutely essential, because of the significant trade off in size and weight when compared to the choke input filter.

The choke input filter configuration was scaled to the remaining power levels of 10, 50, and 100 watts.

<u>Overload and Short Circuit Protection of Booster Regulator Converters</u>

The booster regulator-converter did not contain any inherent means of protection against overload or short circuit conditions. The circuits shown in Figures 9 and 10 were developed as auxiliary circuits for use in providing protection against short circuit and overload conditions. The circuit in Figure 10 provided protection against short circuit conditions, and can be used at all power levels. The circuit in Figure 9 provided both overload and short circuit protection, but thermal considerations limited the use of this circuit to the 10 watt and 25 watt power levels only.

Operation of the short circuit protection circuit of Figure 10 is as follows:

The output terminals of the converter are connected to terminals 1 and 2; the load is connected to terminals 3 and 4. When voltage is first applied

TABLE III

INPUT CURRENT RIPPLE DATA FOR 25 WATT
BOOSTER REGULATOR CONVERTER

INPUT FILTER CONFIGURATION	INPUT CURRENT RIPPLE FOR DIFFERENCE STATES OF OPERATION OF THE DC POWER SOURCE				
	I MA P-P	II MA P-P	III MA P-P	Vol. Cu. In.	Wght. grams
No Input Filter	218	320	230		
Capacitive Input Filter					
C = 82μf	86.3	160	100	.103	8
164μf	57.5*	72.0	64.7	.206	16
246μf	36.0	64.7	43.3*	.309	24
328μf		50.4*		.412	32
Choke Input Filter					
L-5μh, C - 82μf	28.8*	72.0	43.3*	.140	10.5
164μf	14.4	36.0*	28.8	.243	18.5
246μf	7.2	28.8	14.4	.346	26.5
L-12μh, C = 82μf		50.4*	43.3*	.178	12.8
164μf		21.6	21.6	.281	20.8
246μf		14.4	7.2	.348	28.8

NASA Spec No. 63-163 Limit for 25 Watt Booster 60 MA P-P

Operating States of DC Source

I Solar Array/Shunt Regulator - Batteries fully charged floating across the line V - 19.6 VDC

II Solar Array/Shunt Regulator off - Battery delivering power V - 11 VDC

III Solar Array/Shunt Regulator - Charging battery condition Battery and Array supplying power. V = 15 VDC

* Indicates first component within spec limit for given input filter configuration.

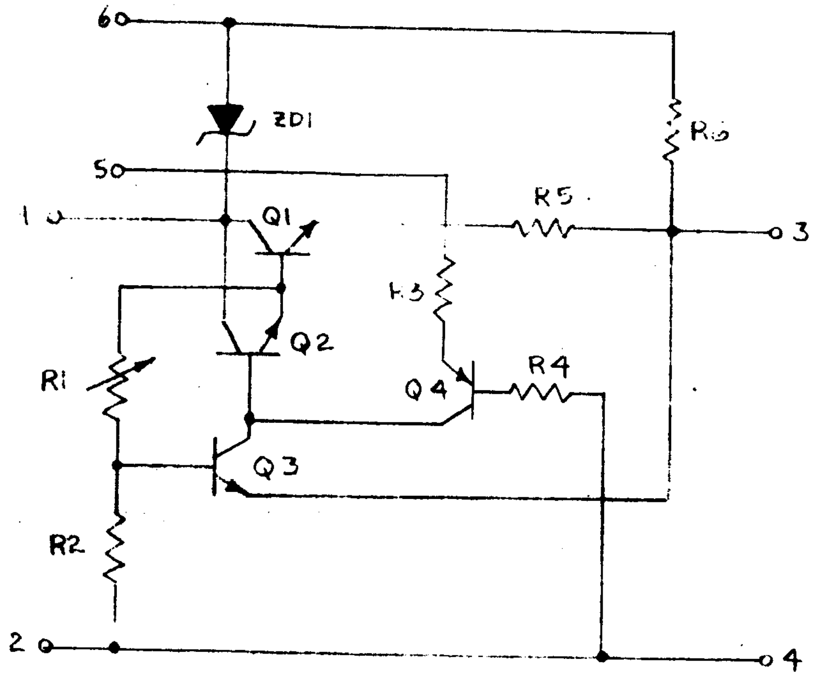


FIG.9 OVERLOAD PROTECTION CIRCUIT

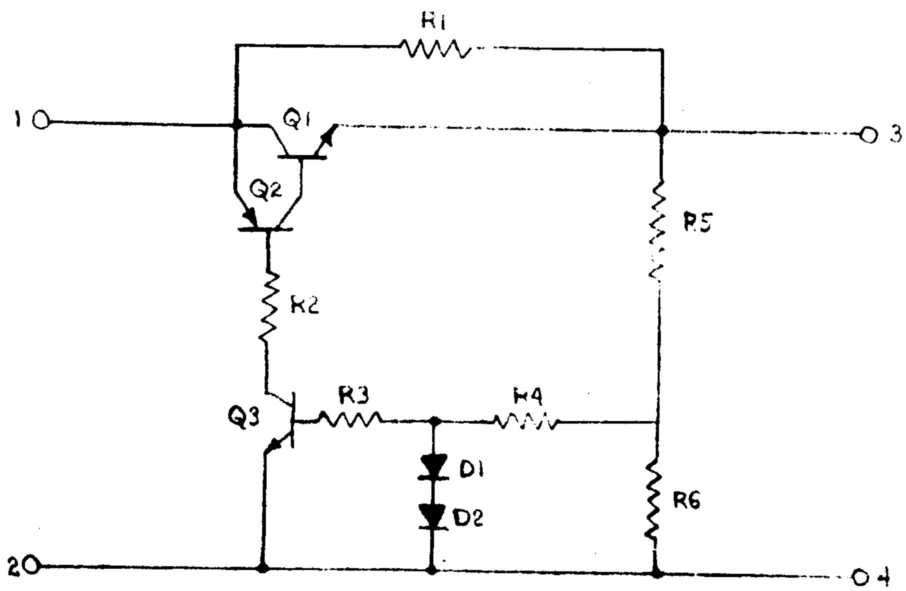


FIG.10 SHORT CIRCUIT PROTECTION SCHEME

across the output of the converter-regulator, transistor Q1 is in a non-conductive stage. A leakage path around transistor Q1 is provided through resistor R1. This leakage is set just high enough to allow sufficient bias to be developed across resistor R6 to turn transistor Q3 on. Transistor Q3 then turns on transistor Q2 which then turns on transistor Q1. Voltage now appears across terminals 3 and 4 and transistor Q1 is driven into saturation; normal operation now occurs.

When a short circuit is applied to terminals 3 and 4, transistor Q1 is forced into a non-conducting state since no voltage can be developed across the resistor combination of R5 and R6. With transistor Q3 non-conducting, transistor Q2 and Q1 are turned off. Thus, with transistor Q1 turned off, the short circuit condition is prevented from being applied across terminals 1 and 2 and isolation from the short circuit is obtained. When the short circuit condition is removed, the circuit automatically returns to the saturated on-state through the starting process described above.

Operation of the overload protection circuit of Figure 9 is as follows:

The output terminals of the converter are connected to terminals 1 and 2, the load is connected to terminals 3 and 4, terminal 5 is connected to an auxiliary B+ voltage, and terminal 6 is connected to the output sensing terminal of the voltage regulator. When the converter is turned on, voltage is applied to terminal 5. The voltage developed across resistor R4 is high enough to turn on transistor Q4, which in turn saturates transistors Q2 and Q1. Voltage now appears at terminals 3 and 4, and normal operation now occurs. Under normal operation, the voltage dividing action of resistor R5 and the load sets the emitter of transistor Q3 at a high voltage. The base voltage of transistor Q3 is set just low enough to keep transistor Q3 in a non-conducting state by the voltage divider consisting of resistors R1 and R2. Zener diode ZD1 is normally in a non-conducting state so that the output sensing of the voltage regulator is connected to terminal 3 through resistor R6.

When an overload condition occurs, the increase in load current causes the voltage across resistor R5 to increase. This causes an increase in the voltage at the emitter of transistor Q1 which in turn raises the voltage at the base of transistors Q1 and Q3. Transistor Q3 turns on, and brings transistors Q2 and Q1 out of saturation. With transistor Q1 out of saturation, the voltage that appears from collector to emitter in transistor Q1 increases, thus increasing the voltage at terminal 1. This forces zener diode ZD1 into conduction, causing the voltage regulator now to keep the voltage at terminal 1 constant. Any further overload increases the voltage drop across resistor R5, decreasing the voltage at terminal 3. This limits the load current by bringing transistor Q3 closer to saturation which in turn forces transistors Q2 and Q1 closer to cut-off. When a short circuit condition occurs, transistor Q3 saturates and drives transistors Q2 and Q1 into a high impedance state, thus isolating the load from the regulator-converter output. When the overload condition is removed, the voltage at terminal 3 increases, turning off transistor Q3, and the circuit automatically returns to the satirated on-state through the starting process described above.

Experimental Data

Efficiency tests were run with the short circuit protection circuit. The efficiency under normal operating conditions averaged about 95% for the short circuit protection scheme for each of the power levels. The losses were divided as follows: Series switch Q1-60%, drive losses for Q1-Q2 in resistor R2 - 20%. The voltage dropped across Q1 was approximately 1 volt; this relatively high voltage drop being caused by the compound connectioh of Q1-Q2. The drive losses related to Q1-Q2 were caused by operating the Q1-Q2 combination at a relatively low gain so that the voltage drop across Q1 could be limited to one volt. The losses associated with the drive for Q3 were a direct result of sizing resistor R5 for the starting requirement rather than the normal loading requirement. The resistor combinations of R1, R5 and R6 were selected such that the dissipation across R1 under short circuit conditions would not exceed the power losses of the converter protection scheme under normal loading.

Tests were conducted to determine the minimum load condition where circuit protection was obtained with the short circuit protection scheme. The following table shows the results of these tests.

Power Level	10 Watts		25 Watts		50 Watts		100 Watts	
Normal Load	48.3 Ω		14.3 Ω		9.8 Ω		12.3 Ω	
Load Required to Obtain Circuit Protection	.66	.32	.56	.38	.29	.18	.13	.08
Input Voltage	10V	20V	10V	20V	12V	20V	22V	33V

Breadboard tests were run using the overload protection circuit with the 25 watt booster to determine the characteristics of the overload protection circuit. The tests were conducted using two values for resistor R1, one providing protection for loads in excess of 105% and the other providing protection for loads in excess of 130%.

Figure 11 shows a graph of the load voltage versus percent of rated output current. With resistor R1 set so transistor Q3 turns on with a 5% overload, it is shown that the output voltage remains constant from no load to approximately 105% load. At this point, the base voltage of transistor Q3 has risen enough to turn on transistor Q3, causing transistors Q2 and Q1 to come out of saturation. The increase in voltage at terminal 1 changes the conduction state of zener diode ZD1 slightly, increasing the voltage regulator sensing current, which causes a small decrease in the voltage at terminal 3. Increasing the load further raises the conduction of transistor Q3 further, which decreases the conduction of transistors Q2 and Q1, and further decreases the output current and voltage. The decrease in output current and voltage is approximately linear from the point at which transistor Q3 begins to conduct, to the short circuit condition. At the short circuit condition, it can be seen that the high impedance state of transistor Q1 allows only about 5% of the rated current to flow.

The percent load at which the overload protection circuit becomes activated and provides overload protection can be adjusted by varying resistor R1. Increasing resistor R1 initially sets the base of transistor Q3 at a lower voltage. Thus, to turn on transistor Q3, the base voltage of transistor Q1, and thus the voltage drop across resistor R5 must be larger than in the previous case. This means that a larger overload must occur before transistor Q3 will turn on and protection will be provided. Note that varying the point at which overload protection is provided has no effect on the output voltage from no load to full load, or at the short circuit condition.

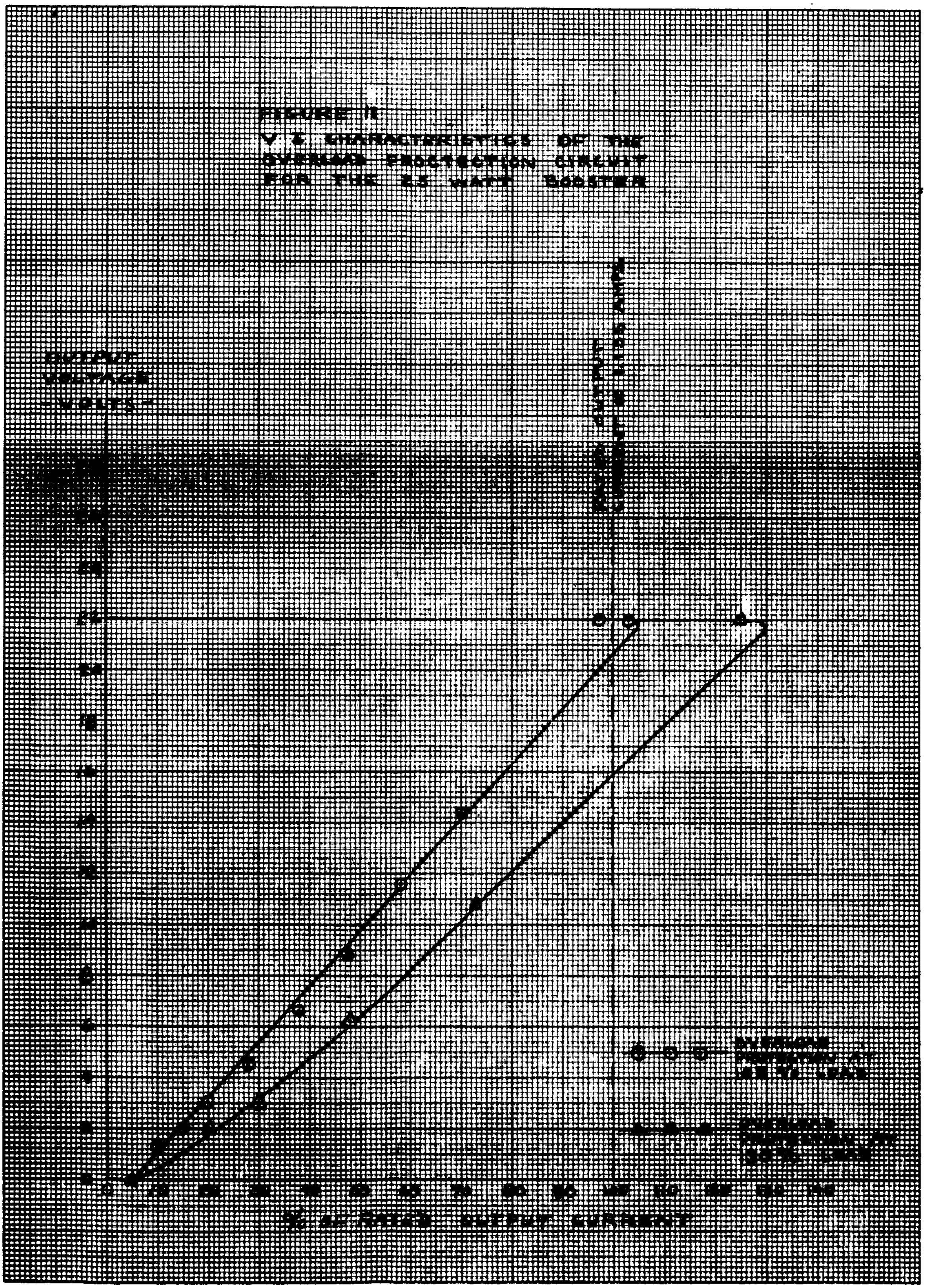


FIGURE 11
V-I CHARACTERISTICS OF THE
OVERLOAD PROTECTION CIRCUIT
FOR THE 25 WATT BOOSTER
OUTPUT
VOLTAGE
-VOLTS-
% OF RATED OUTPUT CURRENT

Figure 12 shows the power dissipation in transistor Q1 versus the percent of rated output current from no load to the short circuit condition for the two overload conditions discussed above. From no load to full load for both cases, the power dissipation increases from essentially zero to approximately one watt at full load. At the point when transistor Q3 is turned on and transistors Q2 and Q1 are brought out of saturation, the power dissipation in transistor Q1 increases sharply. This is due to the sudden increase in the collector to emitter voltage of transistor Q1 with a high collector current present. With additional overload, the load current, and thus the collector current, decreases. However, the collector to emitter voltage increases at a greater rate than the decreasing collector current. Thus, the power dissipation increases further, reaches a peak, and then falls off as the short circuit condition is approached.

For the case where protection is provided for loads in excess of 105%, the power dissipation in transistor Q1 is about 1.5 watts at 105% of rated output current. The peak power dissipation is approximately 9 watts, and the short circuit power dissipation is about 1.5 watts. With the overload protection circuit set for loads in excess of 130%, the power dissipation is approximately 3 watts at 130% of rated output current, 12 watts at peak power dissipation, and 1.5 watts at short circuit.

Preliminary investigations have shown that the peak power dissipation occurs for both cases when the load voltage and the collector to emitter voltage of transistor Q1 are equal. This is in agreement with maximum power transfer theory. Since maximum power dissipation is substantially higher when overload protection is provided at greater loads, a compromise may have to be made between permissible overload and power dissipation in transistor Q1. Also, the ability of the unit to regulate for loads greater than 100% will be determined by the permissible power dissipation of transistor Q1.

Figure 13 shows a graph of the voltage at the input of the overload protection circuit (terminals 1-2) versus the percent of rated output current. The overload protection circuit input voltage increases from 22.6 volts at no load. to 23.5 volts at full load. As expected, it increases suddenly at the point when transistor Q3 turns on, and transistors Q2 and Q1 come out of saturation. This voltage levels off at approximately 25.2 volts when zener diode ZD1 is fully conducting. The effect of the voltage regulator output sensing switch to terminal 1 can be seen from this graph. Switching the sensing to terminal 1 limits the voltage at terminal 1 to 25.2 volts. If switching means were not provided, the voltage at terminal 1 could have risen to almost double its normal value. This

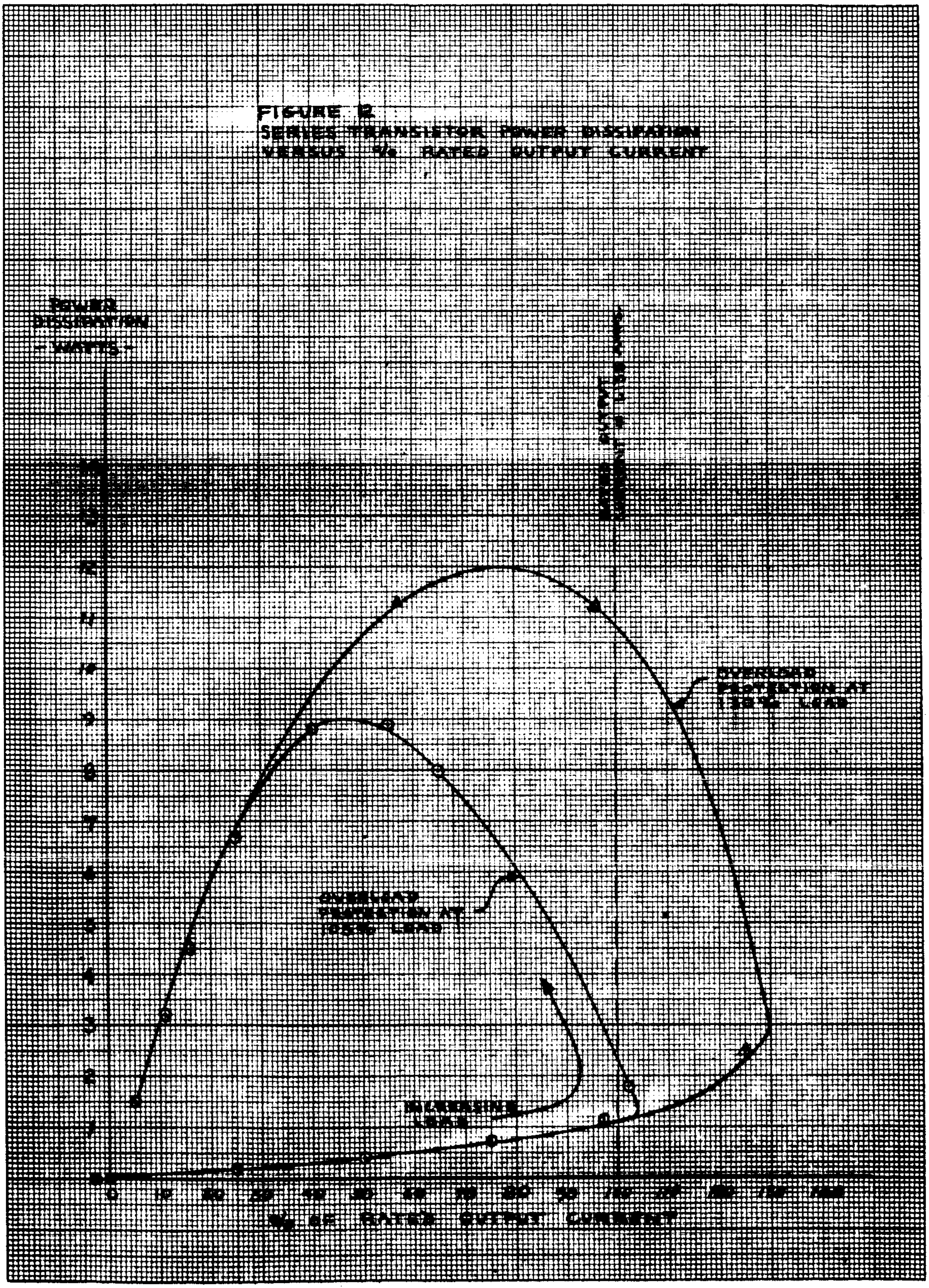
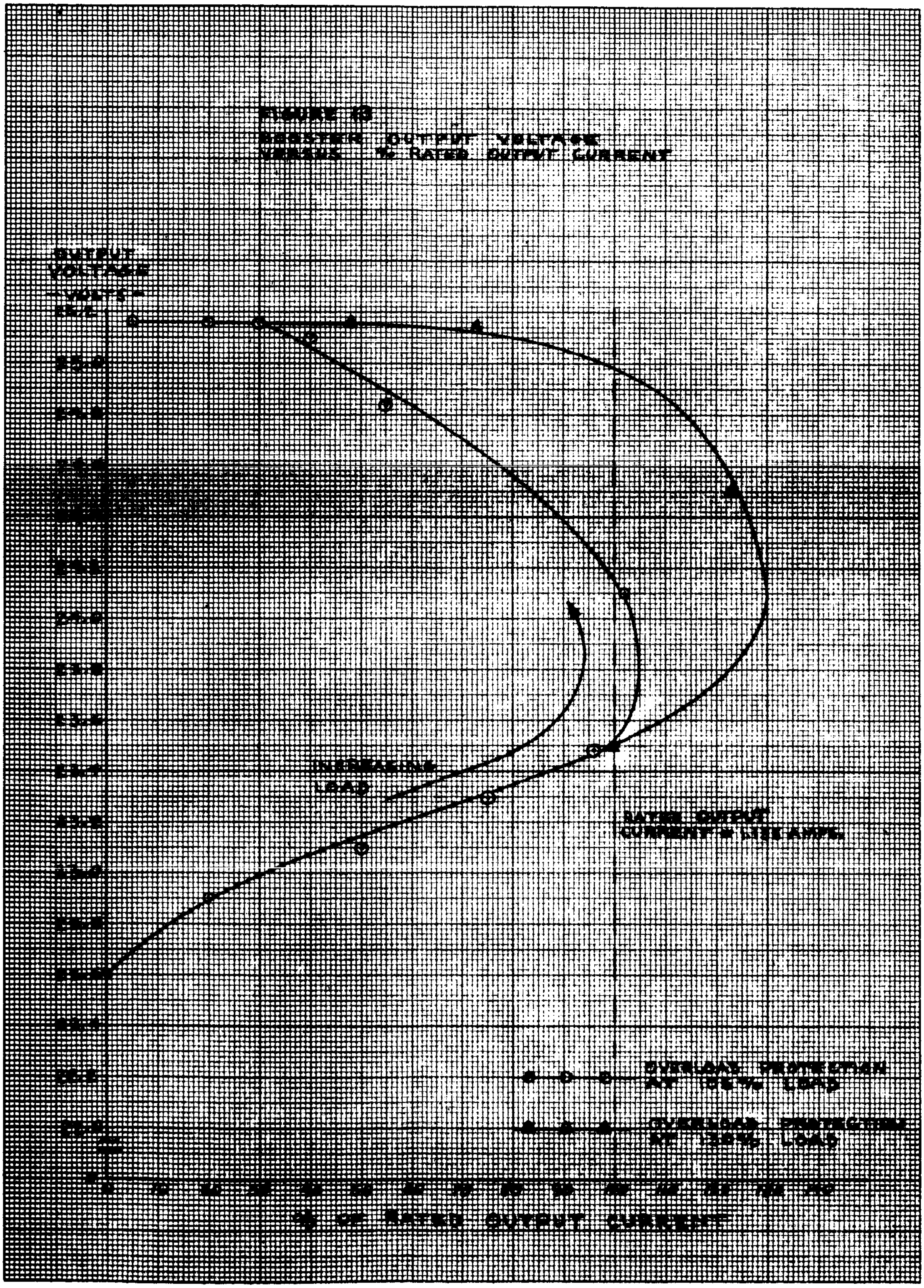


FIGURE 12
SERIES TRANSISTOR POWER DISSIPATION
VERSUS % RATED OUTPUT CURRENT


BOOSTER OUTPUT VOLTAGE
VERSUS % RATED OUTPUT CURRENT
OUTPUT VOLTAGE
INCREASING LOAD
% OF RATED OUTPUT CURRENT

would have required power dissipation in transistor Q1 to be more than twice the maximum reached in the previous tests.

Dynamic Response of the Booster Regulator Converters

Initial investigations showed that the dynamic regulation and recovery time of the booster regulator converters were dependent upon the resistance and capacitance values in the feedback circuit of the voltage regulator. Preliminary breadboard tests were conducted to determine the extent of this dependence.

The circuit shown in Figure 14 was used to produce ramp input voltage changes in the dynamic regulation and recovery time tests. Resistor R1 was set at approximately one ohm. Capacitor C1 was then set so the booster input voltage transient was a ramp change with a slope of one volt per millisecond. With switch S1 open, the booster input voltage was the power supply voltage less the drop across diode D1. When switch S1 was closed, the booster input increased at a rate of one volt per millisecond to the sum of the power supply voltage and the battery voltage less the drop across resistor R1. When switch S1 was opened, the booster input voltage decreased at the same rate to the power supply voltage less the drop across diode D1.

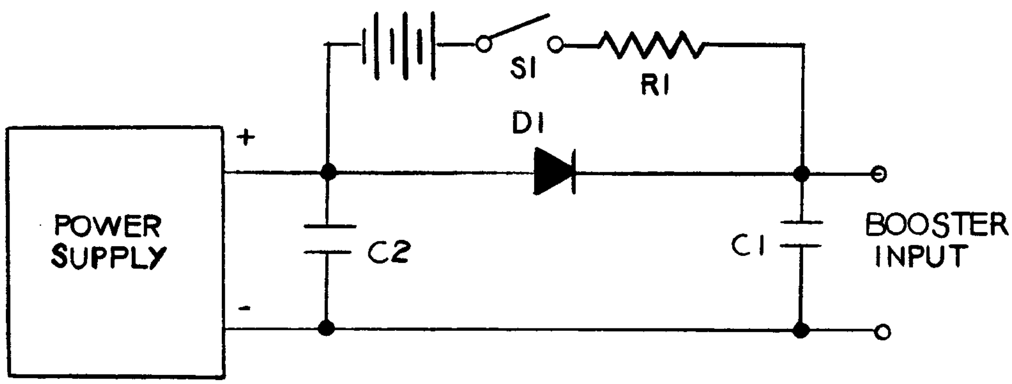


FIGURE 14 INPUT VOLTAGE SUPPLY CIRCUIT FOR DYNAMIC REGULATION AND RECOVERY TIME.

Dynamic regulation and recovery time tests were conducted with the 25 watt booster with both the reference amplifier and the difference amplifier voltage regulator circuits. Input voltage ramp changes and load step changes were both considered in these tests. In the initial testing, both the resistance and capacitance in the compensating circuit of the voltage regulator were varied. The results of these tests showed no significant differences in the dynamic regulation or the recovery time of the reference and difference amplifiers.

A capacitance of 10 microfarads was selected for the capacitor in the compensating circuit of the voltage regulator. Additional tests were then conducted with the resistance in the compensating circuit as the only variable. The results of these tests can be seen in Figures 15 through 18. These results indicated that a trade off between dynamic regulation and recovery time was necessary. For all transient conditions, the peak voltage excursion decreased with increasing resistance. The recovery times for load changes of 100% load to 75% load, and input voltage changes of 10 volts to 20 volts at full load increased with increasing resistance. A resistance of 3 kilohms was selected as a compromise between dynamic regulation and recovery time.

Final dynamic regulation and recovery time tests were run on the 25 watt booster to determine the effect of various input voltage levels on the dynamic regulation and recovery time of the unit. Load changes were made at all input voltages, and input voltage transients were made at three different voltage levels at no load and full load conditions. Dynamic regulation and recovery time were recorded for each case. The results of these tests have been shown in Table IV. The dynamic regulation readings were peak transient voltage values. The recovery time was defined as the time for the output voltage to return to 1% of its original value measured from the beginning of the output voltage transient.

Both the peak transient voltage and the recovery time decreased as the input voltage increased for step load changes. For a load change from 100% to 75% of the rated load, the peak transient voltage was 0.85 volts at 10 volts input. This decreased to 0.50 volts at 16 volts input and remained constant for further increases in input voltage. The recovery time for this case was less than or equal to 10 milliseconds for all input voltages 12 volts or greater. For a load change from 75% to 100% of rated load, the peak transient voltage at 10 volts input was 0.70 volts. This decreased to 0.25 volts at 17 volts input and remained constant for further increases in input voltage. The recovery time for this case was less than 10 milliseconds for all input voltages 12 volts or greater.

Table IV

25 Watt Booster/Reference Amplifier Dynamic Response Data

Lead	Input Volts	Dynamic Response	
		Dynamic Regulation Peak Volts	Recovery Time Milliseconds
E→3/4	10	+0.85	24
	11	+0.75	14
	12	+0.70	10
	13	+0.65	10
	14	+0.60	<10
	15	+0.55	<10
	16	+0.50	<10
	17	+0.50	<10
	18	+0.50	<10
	19	+0.50	<10
	20	+0.50	<10
3/4→F.L.	10	-0.70	22
	11	-0.65	15
	12	-0.60	<10
	13	-0.50	<10
	14	-0.50	<10
	15	-0.40	<10
	16	-0.30	<10
	17	-0.25	<10
	18	-0.25	<10
	19	-0.25	<10
	20	-0.25	<10
N. L.	9.5→20.6	+0.30	12
	11.2→20	+0.10	--
	13.25→20	-0.25	30
N. L.	20.6→9.5	+0.70	50
	20.0→11.2	+0.60	18
	20.0→13.25	+0.55	23
F. L.	10.5→20	-1.0	40
	12.8→20	-0.40	28
	15 20	-0.30	24
F. L.	20→10.5	+1.25	38
	20→12.8	+0.70	24
	20→15	+0.50	22

Dynamic response design goals
Dynamic regulation: ± 0.66 volts
Recovery time" 50 milliseconds

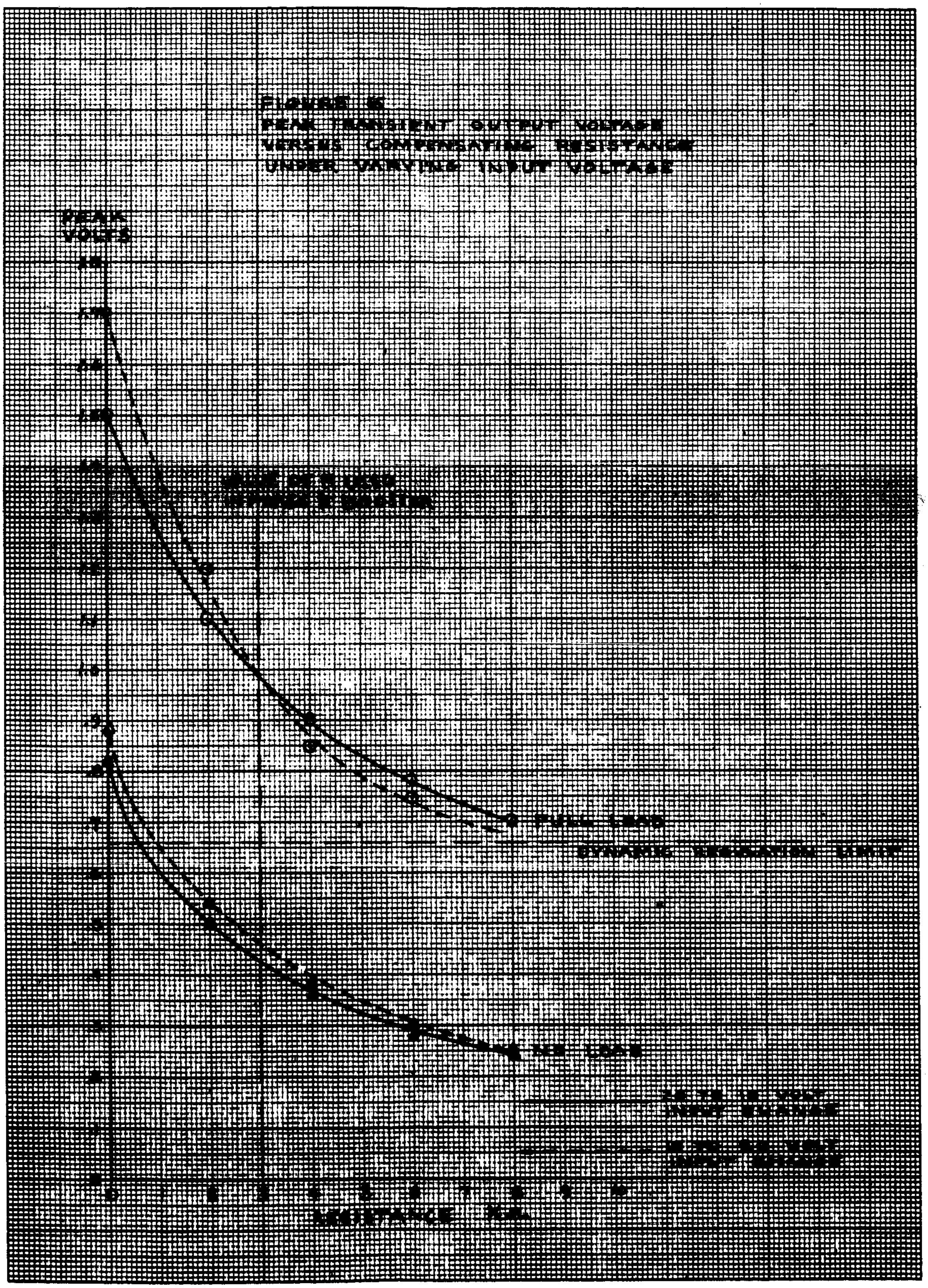


FIGURE
PEAK TRANSIENT OUTPUT VOLTAGE
VERSUS COMPENSATING RESISTANCE
UNDER VARYING INPUT VOLTAGE
PEAK VOLTS
FULL LOAD
NO LOAD
RESISTANCE K

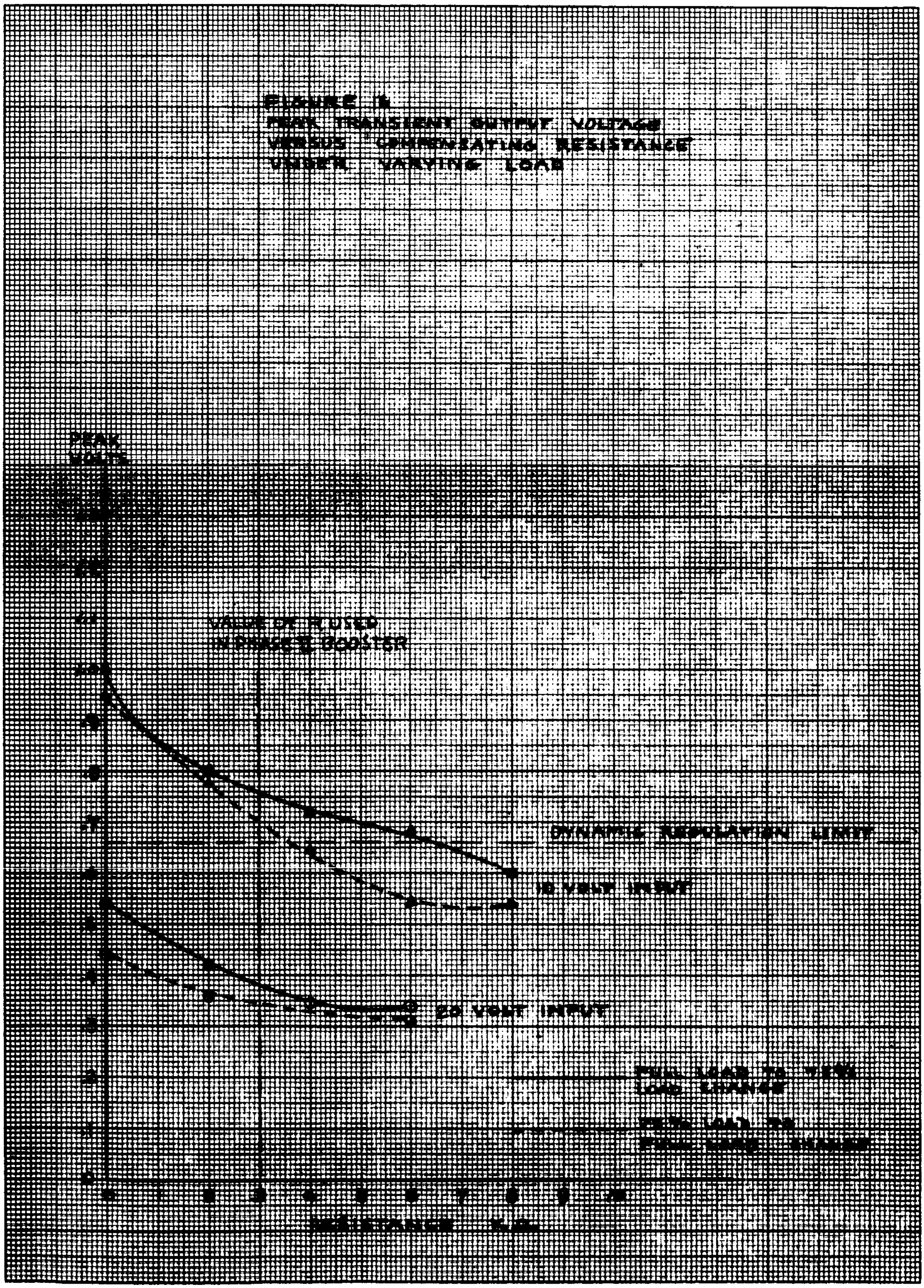


FIGURE
PEAK TRANSIENT OUTPUT VOLTAGE
VERSUS COMPENSATING RESISTANCE
UNDER VARYING LOAD
PEAK
VOLTS
VALUE OF R USED
IN PHASE II BOOSTER
DYNAMIC REGULATION LIMIT
10 VOLT INPUT
20 VOLT INPUT
RESISTANCE

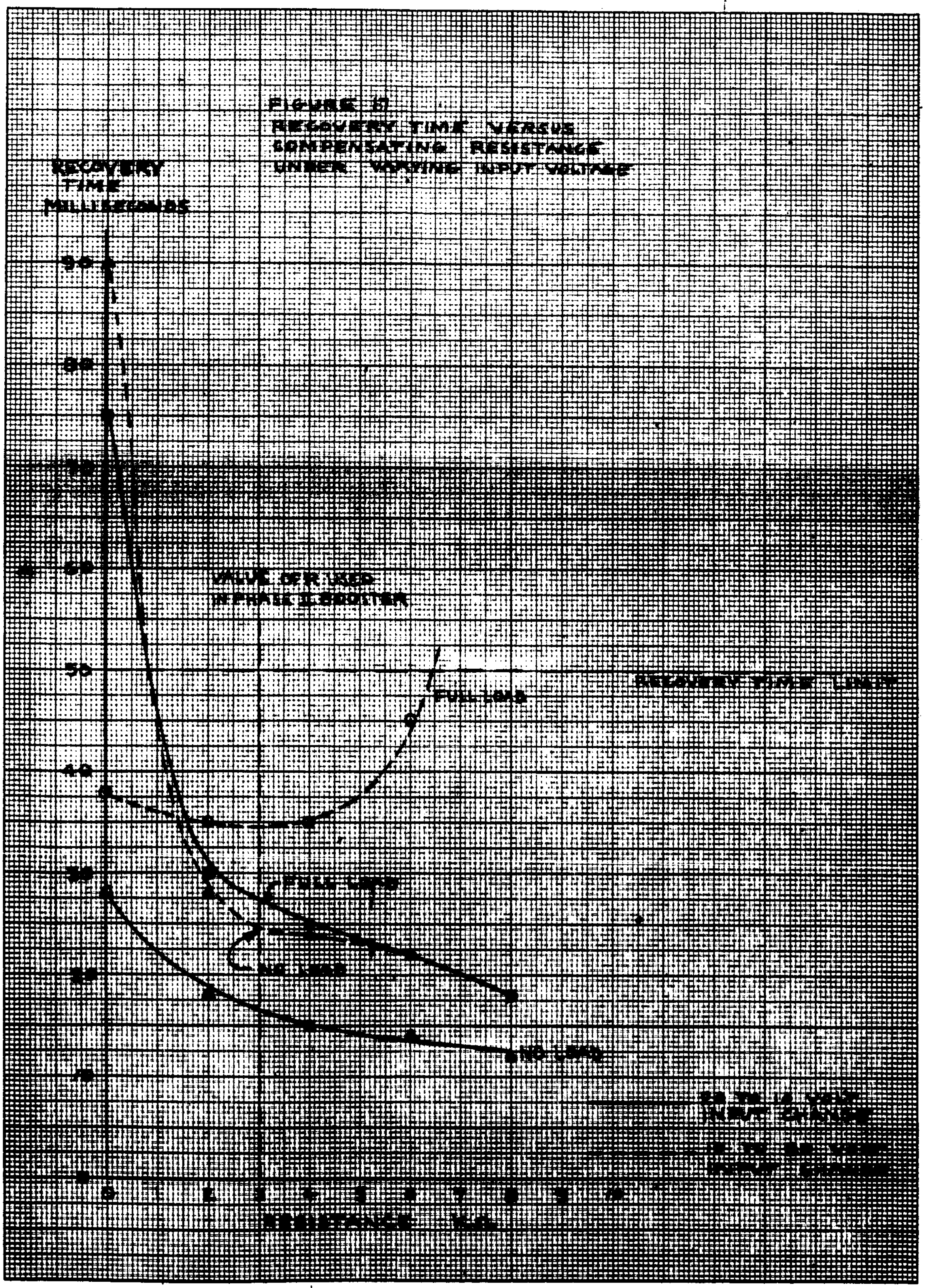
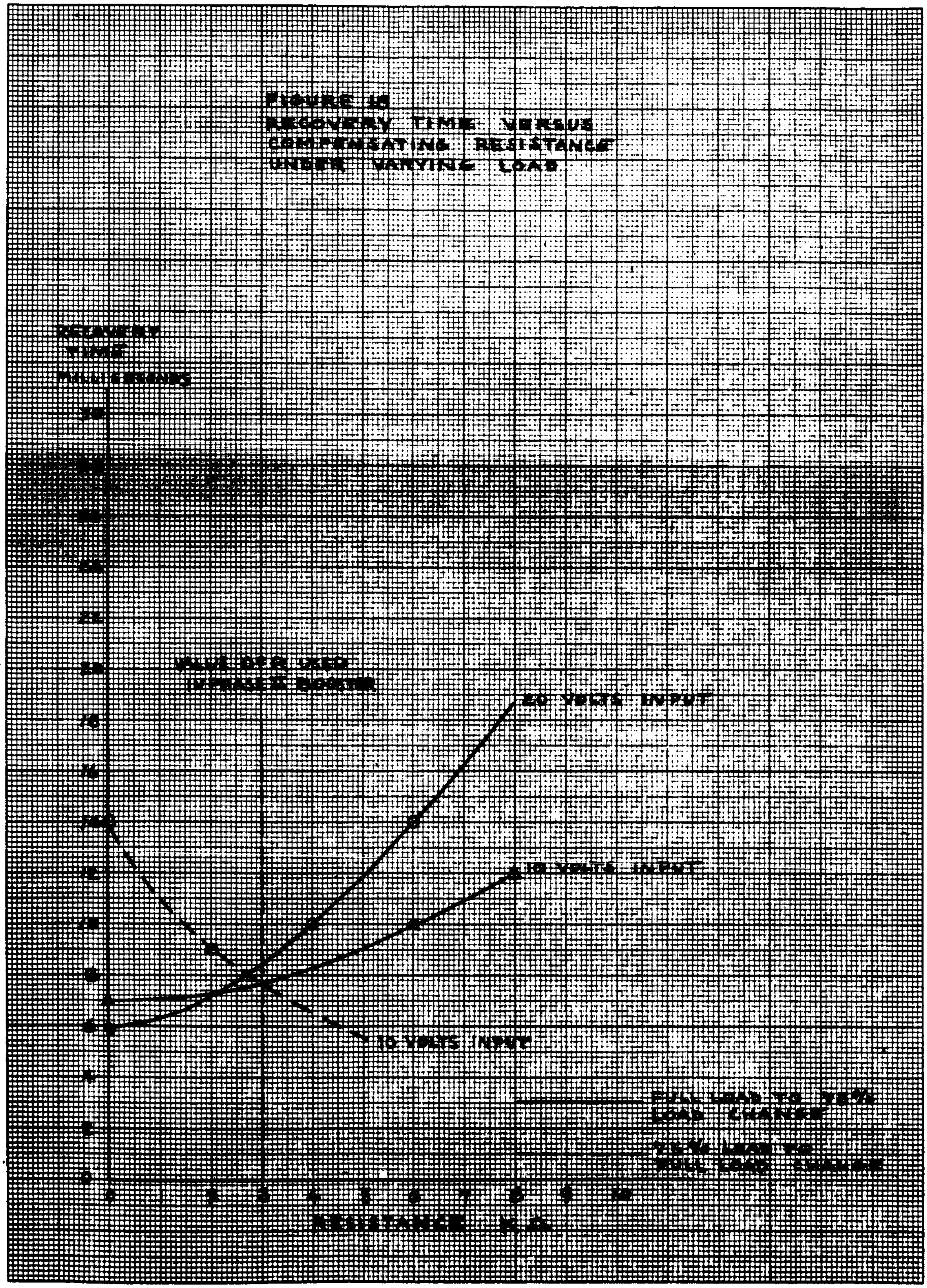


FIGURE 17
RECOVERY TIME VERSUS
COMPENSATING RESISTANCE
UNDER VARYING INPUT VOLTAGE
RECOVERY
TIME
MILLISECONDS
90
80
70
60
50
40
30
VALUE OF R USED
IN PHASE II BOOSTER
RECOVERY TIME LIMIT
FULL LOAD
FULL LOAD
NO LOAD
NO LOAD
RESISTANCE


RECOVERY TIME VERSUS
COMPENSATING RESISTANCE
UNDER VARYING LOAD
20 VOLTS INPUT
10 VOLTS INPUT
10 VOLTS INPUT
0 1 2 3 4 5 6 7 8 9 10
RESISTANCE

For input voltage changes at no load and full load conditions, the peak voltage transient and the recovery time decreased as the low input voltage level was raised for all cases with one exception. For the no load condition with input voltage changes from low voltage to 20 volts, the peak voltage transient and recovery time were smallest for a change of 11.2 volts to 20 volts. In this case, since the peak voltage transient did not reach 1% of the output voltage, the recovery time was considered to be negligible. Note that for no load input voltage changes, two cases exist where the input voltage limits of the booster have been exceeded. This was due to the state of the charge of the battery, and the fact that the battery voltage was adjustable only in steps of approximately two volts.

For input voltage changes, two cases occurred where the peak voltage transient was abnormally large. For the full load condition with input voltage changes of 10.5 to 20 volts, and 20 to 10.5 volts, the output voltage transients were 1.0 volt and 1.25 volts respectively. The recovery time did not exceed 50 milliseconds for any of the transients investigated. In three cases, however, it did approach this maximum. For full load, 10.5 to 20 volts input change, the recovery time was 40 milliseconds. For full load, 20 to 10.5 volts input change, the recovery time was approximately 38 milliseconds. For the no load condition, 20.6 to 9.5 volt input change, the recovery time was approximately 50 milliseconds. Note, however, that this was one of the cases where the input voltage requirements of the booster were exceeded.

Final Circuit Configuration

For the final closed loop control, the controlled charge rate sawtooth/ Schmitt trigger pulse width modulator has been selected. The reference amplifier has been selected as the voltage regulator. Regulation is obtained by varying the charge rate of the sawtooth former, consisting of R12, Q3, C4, and Q4, as shown in Figure 19.

The charge rate is controlled by varying the bias on the base of transistor Q2, which in turn changes the bias on transistor Q3 and thus its conductivity. When Q3 conducts more, capacitor C4 charges more rapidly and the pulse width of the Schmitt trigger, consisting of transistors Q6–Q8, resistors R17-R24, and diode D2, is changed.

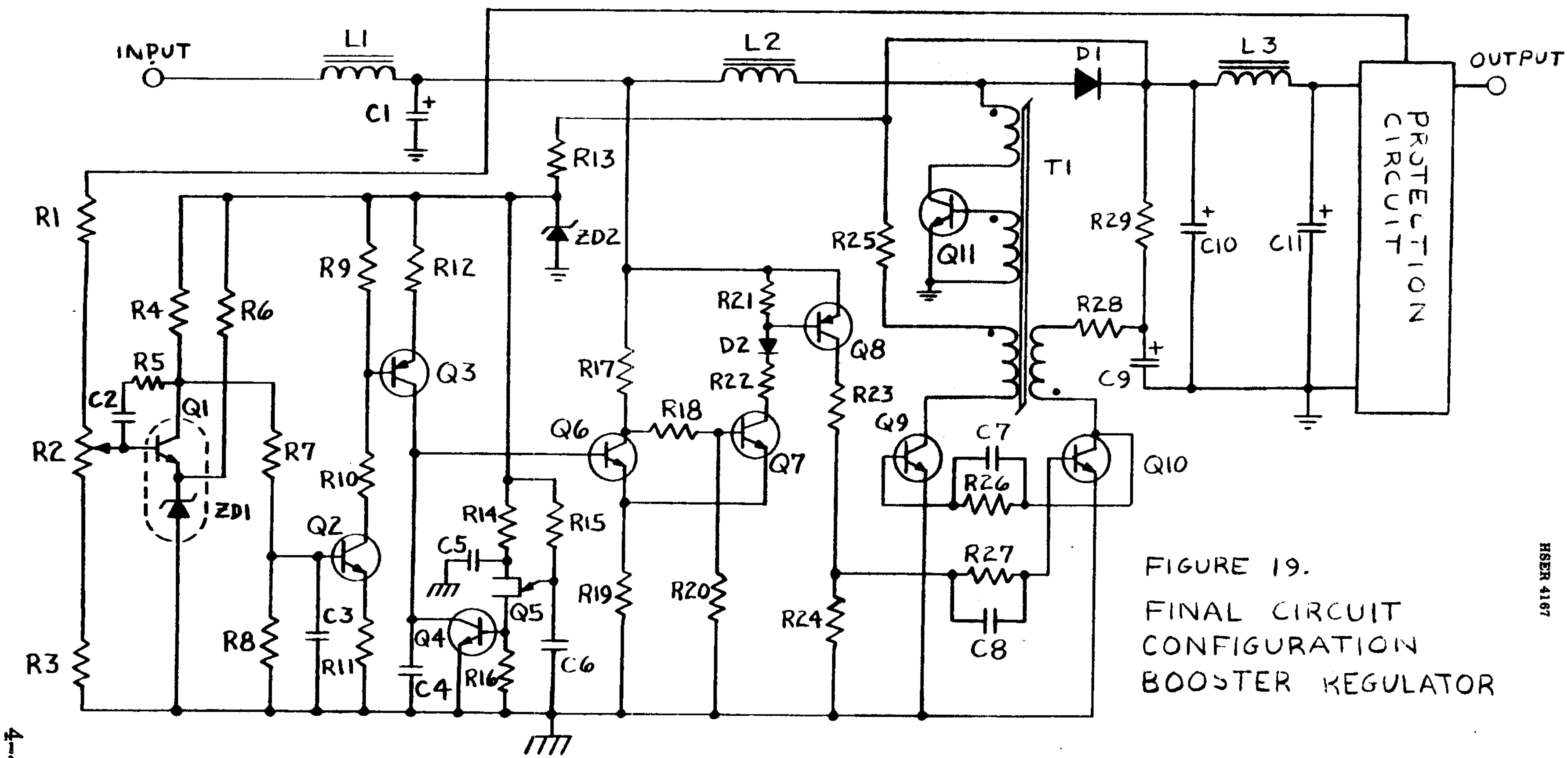


FIGURE 19.
FINAL CIRCUIT CONFIGURATION BOOSTER REGULATOR

The controlling sense of this circuit is most easily described by assuming a momentary change in output voltage and determining the corrective action required to return the output voltage to its normal state. If the output voltage of the booster is assumed to drop momentarily, the base of the sensing transistor Q1 in the voltage sensing amplifier drops, but its emitter voltage is held constant to a reference voltage thus causing its collector voltage to rise. The rising collector voltage of the sensing transistor causes a rise in the base voltage of transistor Q2, which in turn causes,the collector voltage of Q2 to drop. This lowers the base voltage of Q3, thus increasing its conductivity. The increase in conductivity increases the charge rate of C4 which increases the on-time of Q6 in the Schmitt Trigger. The on-time of Q6 corresponds to the off-time of Q8, thus the voltage across R24 is high for a shorter period of time.

The base of the reset transistor Q10 is connected to R24, thus it is turned off for a longer period of time. When Q10 is off the main switching transistor, Q11 is on, and it has been shown that increasing the on-time of Q11 causes an increase in the output voltage. Thus the output voltage has been compensated for its initial drop-off and has resumed its normal state.

4.5 Development of Chopper Regulator - Phase II

Investigations were initiated into the development of a new set of chopper regulator converters using the control concepts developed for the booster regulator converters. The new circuit configuration shown in Figure 20 is similar in operation to Phase I booster regulator converters.

Fundamentally, the chopper is a power stage, made up of transistor Q, diode D, inductor L, and capacitor C; and a control circuit consisting of a current feedback transformer, reset and trigger transistors, a Schmitt trigger, and a ramp generator. The power stage operation can best be described by the unified power stage concept described in Appendix II. When Q is on, D is back biased and current flow builds up through L; and the energy stored in L is discharged through D into C and the load. The energy delivered to the load, and thus the output voltage, can be controlled by varying the duty cycle of Q. The control circuitry functions identically to the boosters, but the different duty cycle and voltage level requirements introduce new considerations.

The unified power stage concept indicated that many booster components could be interchangeable with choppers operating at comparable voltage and current levels. All the booster and chopper chokes are identical except that the

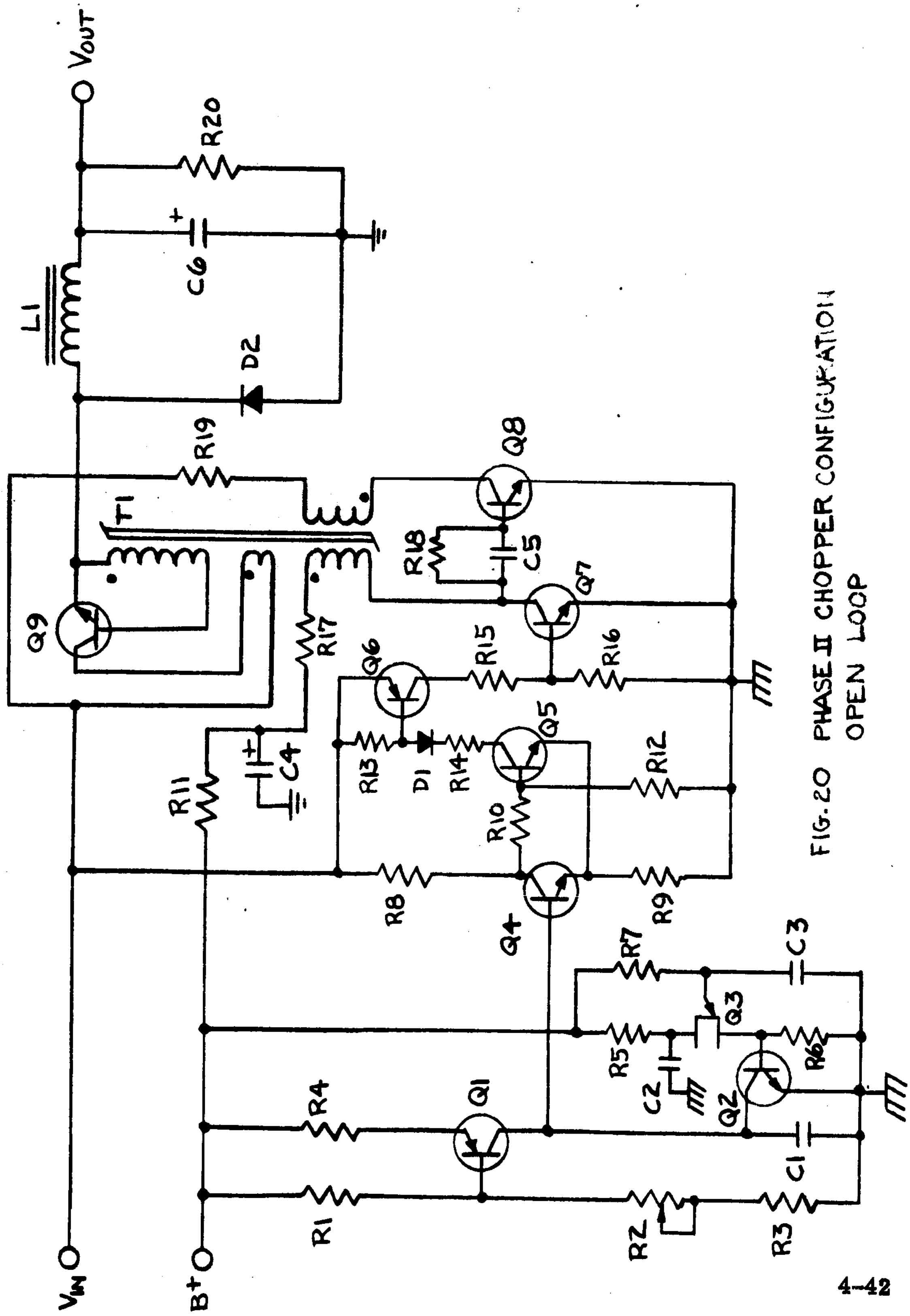


FIG. 20 PHASE II CHOPPER CONFIGURATION
OPEN LOOP

low power boosters have an additional winding for overload protection. This is because the maximum current levels are the same for given power levels, thus requiring a common wire size, as well as similar inductance requirements. The power transistors have the same peak current, the same V_{CEO} requirements, and differ only in V_{eb} rating which is a result of the control circuitry used. The power diodes are the same peak inverse voltage and same peak current, but differ only in average current rating. The output capacitors of the booster would have similar characteristics to the input capacitors of the choppers, and the output capacitors of the choppers would be similar to the input capacitors of the boosters. The choppers have not been developed to the point where these componenst have been defined enough to compare them. Theoretically, the DC voltage rating, the ripple voltage rating and the approximate capacitance would be the same for the respective sets that correspond on the unified power stage approach.

Development Effort - Open Loop Control

The prime problem encountered in the development of new chopper converter regulators was achieving reliable operation as the input voltage magnitude approached the output voltage magnitude. Under this condition, with the control circuitry being used, the reset time of the current feedback transformet becomes very short, thus requiring large voltages to reset the driver core. The increased voltage requirement gave rise to two problems.

1. It required more pulse power in the reset circuitry
2. It raised the emitter-base voltage seen by the power transistor during reset.

For example, for an input of 10 volts and an output voltage of 9 volts, the reset time would be less than 10% of the total period. This means that during reset the emitter-base junction could be subjected to as much as 12 volts, or 4 volts over the rated value for the components presently being used.

Related to this was the problem of having to turn on the trigger early in each cycle; there is delay time associated with the unijunction oscillator caused by the discharge time of the oscillator output pulse, and at high frequencies this becomes a considerable portion of a cycle. Since the trigger cannot be turned on until the unijunction has reset the ramp generator, this discharge time becomes a limiting factor.

It was decided that the limits on the input voltage or output voltage would have to be changed to alleviate this problem. The following limits were chosen:

10 watt chopper 12 to 20 volt input, 9 volt output
25 watt chopper 12 to 20 volt input, 9 volt output
50 watt chopper 14 to 20 volt input, 11 volt output
100 watt chopper 24 to 33 volt input, 20 volt output

With these changes, the choppers were operable, but it should be noted that the peak emitter base voltages are still close to the maximum rated values of standard high frequency power transistors.

Supplying a regulated voltage for the control circuitry presents another problem; a regulated voltage can be obtained by regulating the input voltage or by using the already regulated output voltage. Efficiency considerations indicate that the output should be used, but because there is no voltage at the output until the control circuitry is running, a starting circuit is necessary.

Development Effort - Closed Loop Control

Initial investigations were made in operating the chopper boards in a closed loop mode, and the circuit as shown in Figure 21 was operated satisfactorily. The circuit is similar to the open loop choppers, but a starting circuit and reference amplifier have been added. This unit was not short circuit protected, and did not regulate within ± 1%, but it demonstrated preliminary closed loop regulation and was used to investigate closed loop chopper operations.

Operating the chopper closed loop presented two main problems:

1. Control voltage and related starting problems.
2. Short circuit protection.

The voltage for the control circuitry must be regulated, and could be taken from a zener regulated supply at the input of the chopper or directly off the output terminals. The zener regulated approach is simple but inefficient as the input voltage varies over a wide range, and it has the additional disadvantages of being necessarily lower than the lowest input voltage. The alternate method of using the output voltage is efficient and simple except that it creates a starting problem; that is, until the unit is running there is no output, and the unit

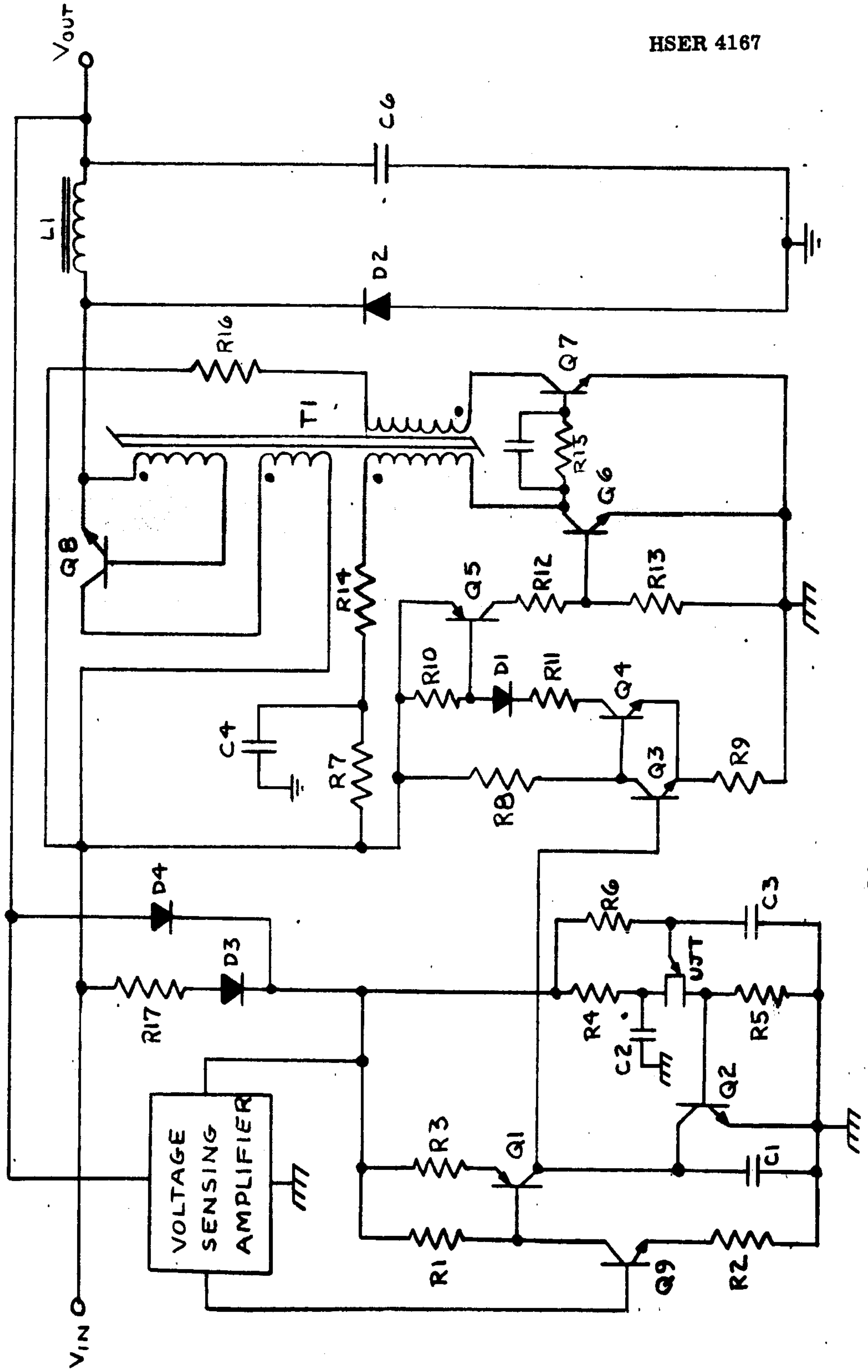


FIGURE 21. REVISED CHOPPER REGULATOR CONVERTOR WITHOUT SHORT CIRCUIT PROTECTION

will not start properly without control voltage. This starting problem can be solved by using two diodes (D3, and D4 in Figure 21) to alternate the supply from the input to the output as the chopper reaches nominal output voltage. In this manner a control voltage is supplied efficiently and simply.

The second major problem is short circuit protection, and again a starting problem is involved. The most direct way to protect these units is to turn off the series element during extreme overload, and this can be accomplished simply by supplying the trigger winding from the output of the chopper; thus, when the output drops off (as it would at some critical overload) the trigger voltage would decrease and would not be capable of turning on the series element. This method creates the need for a starting voltage on the trigger, however, and indicates a current sensing element would be necessary for the circuit to differentiate between low output voltage under starting and low output voltage during overload. The chopper has been run with the trigger operating off the output, and short circuit protection was obtained, but no development has been done in the area of the current sensing starting circuit, so the unit being tested had to be "artificially" started.

An alternate approach of adding an auxiliary series protection element as in the boosters was considered, but any device of this type would add a sizable voltage drop to the chopper and would compound the problems associated with large duty cycles as explained in the open loop development section. This method could not be considered for further development because of the funding limitations of the program.

4.6 Breadboard Testing and Evaluation

Selected performance tests were run on the four booster breadboards. The following tests were performed on each power level:

1. No load losses
2. Efficiency
3. Static closed loop regulation
4. Output ripple voltage
5. Input current ripple
6. Dynamic Response
7. Extended operation
8. Short circuit protection

Performance curves from the test data are included in Appendix III Included with the performance data is a general analysis of the booster characteristics. A component size and weight summary for the booster is given in Appendix V.

Selected performance tests were run on the four open loop chopper breadboards. The following tests were performed on each power level:

1. No load losses
2. Efficiency
3. Open loop regulation
4. Output ripple voltage
5. Input ripple current

Performance curves from the test data are included in Appendix IV. Included with the performance data is a general analysis of the chopper characteristics.

4.7 Modularization

The overall objective of this program was to satisfy the anticipated satellite power conversion system requirements by utilization of modularization concepts for the power conversion circuits. The anticipated modular breakdown consisted of: A regulator-converter module for obtaining voltage regulation and control for DC source variations; DC to DC conversion modules for obtaining isolation, voltage transformation, and multiple output voltages; output regulator modules for providing the required matching characteristics to the load. The present program was limited in scope to modularization of the non-dissipative regulator-converter portion of this system.

The original goals set forth in this program were modularization with respect to output voltage level, and to output power level. Modularization with respect to output voltage level was divided into two groups, one group being those converters having output voltages less than the minimum input voltage, and the second group being those converters having output voltages greater than the maximum input voltage. The converters in these groups were categorized as either choppers or boosters respectively. Modularization with respect to output power level was made at the output power levels of 10, 25, 50, and 100 watts.

The direct result of this modularization approach was to pursue separate programs of development for the chopper regulator converter and for the booster regulator converter. Each of the regulator-converter concepts were to be capable of being scaled to the desired output power levels. Modularization within each converter concept was established as a goal wherein specific signal and control circuits could be made independent of power level. Achievement of this goal would enable these circuits to be utilized at any power level.

The modularization goals achieved during the Phase I program for the chopper regulator were:

1. Scaling with respect to power level was possible.
2. Selection of components for the power stage, driver stage, and filter stage was power dependent.
3. Circuits common to all power levels were restricted to the variable frequency source and the chopper transistor gate circuit.

The modularization goals achieved during the Phase I and Phase II programs for the booster regulator were:

1. Power Stage - Selection of components was power dependent, but scaling with respect to power level was possible.
2. Input/Output Filters - Selection of components was power dependent, but scaling with respect to power level was possible.
3. Driver Circuit - Selection of components was power dependent, but scaling with respect to power level was possible.
4. Pulse Width Modulator - Circuit components are identical for all power levels operating at the same voltage level. Scaling with respect to voltage level was possible for the higher voltage unit.
5. Oscillator - Circuit components are identical for all power levels operating at the same voltage level. Scaling with respect to voltage level was possible for the higher voltage unit.
6. Voltage Regulator - Circuit components identical for all power levels operating at the same voltage level. Scaling with respect to voltage level was possible for the higher voltage unit.

The modularization goals achieved during the Phase II program for the chopper regulator were:

1. Scaling with respect to power level was possible.

2. Selection of the components for the power stage, driver stage, and filter stage was power dependent.
3. The oscillator and pulse width modulator circuits were identical for all power levels, but scaling with respect to voltage level was required.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Chopper Regulator - Phase I

The final configuration selected for the power stage for the chopper-regulator series was the single-ended self-stabilizing chopper. External gate triggering was selected as the most suitable means of circuit starting. The degenerative feedback method of current limiting was shown to be the most effective method of improving circuit recovery time. This method of current limiting required a significantly larger range of operating frequency to maintain output voltage control.

At the completion of this phase of the program it was recommended that further development effort on this chopper circuit configuration be discontinued. The problems associated with circuit starting and current limiting required that complex auxiliary circuits be used to obtain proper performance of the basic power stage. In addition, major effort was still required to obtain good inherent line regulation because of the turn off problem of the main chopper transistor. Also, the undue control circuit complexity, required to satisfy the electrical requirements, resulted in the failure of this circuit to achieve the modularization goals. Development of these breadboards was conducted only to the extent of obtaining satisfactory static open loop performance.

5.2 Booster Regulator - Phase I

The final circuit configuration selected for the power stage for the booster regulator series was the single-ended flyback booster controlled by a line compensated variable pulse width modulator. The results of the preliminary frequency-efficiency data indicated that 30 KHz was a reasonable operating frequency consistent with minimum size and maximum efficiency.

Selected performance tests on 10, 25, 50, and 100 watt breadboards showed the following general characteristics: efficiency varied from 88% to 95% dependent upon the power level; the open loop voltage regulation was typically ± 3% for complete input line variations and for load variations of 25% rated load to 100% rated load. The overload test indicated that there was no short circuit protection. The output voltage dropped off due to IR drops as the load increased, but the drop-off was not sufficient to protect the unit or its source. Both input ripple current and output ripple voltage were considerably higher than allowable. This indicated that either a larger choke and output capacitor were necessary, or supplementary L-C filters would have to be added to the input and output of the booster power supplies.

It was recommended that the single-ended flyback booster concept be further developed in the Phase II program.

5.3 Booster Regulator - Phase II

The final circuit configuration selected for the booster regulator converter is similar to the open loop boosters of the Phase I program, with the addition of a reference amplifier voltage regulator, input and output ripple filters, and overload and short circuit protection circuits. Size and weight reduction of the flyback choke was achieved by utilizing the swinging choke effect. The LC filter section was selected as the optimum input filter. The pi filter section was selected as the optimum output filter.

A short circuit protection circuit was successfully developed for the 50 watt and 100 watt boosters. An overload protection circuit was successfully developed for the 100 watt and 25 watt boosters. A compromised design was achieved between static regulation performance and dynamic regulation performance.

The following conclusions are based upon the selected electrical performance data obtained on the four booster breadboards. The efficiency tests on the boosters showed that maximum efficiency occurred at full load and approximately mid line as in the open loop versions. They also pointed out that the protection circuits were from 90% to 96% efficient at full load. The peak efficiencies for the 10, 25, 50, and 100 watt boosters were 82.6%, 88.6%, 91.0% and 92.6% respectively. These efficiencies were lower than in the Phase I boosters due to control circuit losses and the additional losses incurred by operating the chokes into saturation. The no load losses were relatively independent of power level, but were much higher for the 100 watt unit which operated at a higher voltage and required a 2% bleeder at no load. The lower power boosters required no bleeder loads.

The closed loop static regulation tests showed that all boosters regulated to well within the ± 1% band specified for line, load and ambient variations with and without protection circuits.

The closed loop dynamic regulation investigations revealed that some of the dynamic characteristics were beyond the desireable limits; the time responses were all within specified values, but the voltage excursions for load change were, in general, 3% of the output voltage and the excursions for line changes were about 5% of the output with the largest excursion occurring at full load and 20 to 10 volt line change.

The input and output ripple was well within the specified limits for all power levels as a result of the input and output filters added to the Phase I boosters.

The short circuit and overload protection devices operated satisfactorily in all cases, but did reduce efficiency as previously described.

The extended operation test indicated excellent stability over the 40 hour test period with negligible drift in the output voltage.

5.4 Chopper Regulator - Phase II

At the completion of the Phase I program, it was recommended that the basic control concept developed for the booster power supplies be applied to a new series of chopper power supplies.

The Phase II chopper breadboards were designed from the unified power stage concept. The pulse width modulator and oscillator developed for the booster power supplies were successfully adapted to the Phase II series of chopper power supplies. The open loop control problems were resolved by limiting the input voltage range fo narrower limits. However, the emitter base voltage rating limitation of the main chopper switch has not yet been resolved.

The preliminary investigations into closed loop control showed two related problems; that of circuit starting, and that of circuit protection. The choice of solution to the circuit protection problem could dictate the solution to the starting problem.

The following conclusions are based upon the selected electrical performance data obtained on the four chopper breadboards. The efficiency tests on the chopper breadboards showed that maximum efficiency occurred at low line and light loads; the maximum efficiency measured for the 10, 25, 50 and 100 watt choppers were 94.3%, 94.5%, 94.5%, and 97.9% respectively. These numbers are considerably higher than the closed loop boosters, because all the circuitry normally run from a regulated supply within the unit was operated from an external supply and these losses were not taken into account. The no load losses for the choppers were approximately proportional to the power level, because 5% bleeder loads were used. The additional losses were primarily in the reset circuitry.

Open loop regulation for line and load was considerably better than the Phase I choppers, and the total variations for the 10, 25, 50, and 100 watt choppers were 3.8 volts, 5.3 volts, 6.4 volts, and 6.3 volts respectively.

The output ripple voltage was well within specified limits except for the 100 watt unit which was 50% over the desired value. This was due primarily to capacitor selection and could be easily remedied.

The input current ripple for the choppers was relatively large and will require an input filter, to make it acceptable. The data presented was taken with no input filter to the choppers, thus the resultant input ripple current was a square wave as predicted by the unified power stage approach.

5.5 Overall Recommendations

Booster Regulator Converters

The essential breadboard development of the booster regulator converter has been completed. Thus two possible programs of follow-on effort can be recommended.

1. Packaging of the present booster regulation converter into flight worthy hardware.
2. Continuation of the breadboard development effort towards the modulatization goals previously described.

An outline for these programs is provided in Appendix VI.

Chopper Regulator Converter

Significant development effort remains to be done on the chopper regulator converters. The problems associated with closed loop control, circuit starting, and circuit protection have been briefly investigated during the present program. The selected electrical performance data on the Phase II choppers has shown that these units possess potentially high efficiency, tight output voltage control and low input and output ripple. Therefore, it is recommended that further development be made with this series of power supplies to achieve complete closed loop control.

Buck-Boost Regulator Converters

The present program has limited itself to investigations of boost type and chopper type power supplies prodicing regulated output voltages slightly above the maximum input voltage, or slightly below the minimum input voltage respectively. There exists another type of power supply commonly termed the "buck-boost" system having capability of providing a regulated output voltage at any desired point between the minimum and maximum input voltage, and having capability of providing all of the desireable output characteristics of the booster and chopper converter systems investigated in the present program. Therefore, it is recommended that a study and development program be considered for this type of regulator converter.

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7.0 CONFERENCES

On July 5, 1964, a conference was held with Messrs. Yagerhofer and Pascuitti of NASA Goddard. Discussion concerned program progress, philosophy of the study, and a review of the literature search. The criteria for selection of circuitry was reviewed and weighting factors established.

On September 25, 1964, a second conference was held with Mr. Pascuitti. Program progress was discussed, and a rough draft of the first quarterly report was reviewed. It was decided that the original program plan should be modified somewhat, with the aim of performing most of the analytical and feasibility investigations before any formal breadboard work was initiated.

A conference was held at NASA, Goddard on July 1, 1965. In attendance were Messrs. F Yagerhofer and E. Pascuitti representing NASA, and Messrs. E. Trifari and F. Raposa representing HSED. Technical status and contract status of the program were reviewed. Program extension for the Phase I program and initiation of the Phase II program were discussed and agreed upon.

A conference was held at NASA Goddard on November 29, 1965. In attendance were Messrs. F Yagerhofer, E. Pascuitti and G. Burgholder representing NASA, and Messrs. E. Trifari and F. Raposa representing HSED. The outline for the final project report for the Phase I program was reviewed and approved by the NASA technical representatives.

Technical status of the booster concept effort then in process was discussed in detail. A reqest for contract modification was submitted for retention of the breadboards from the Phase I program for the remainder of the phase II program.

A conference was held at NASA Goddard on February 21, 1966. In attendance were Messrs. F Yagerhofer and E. Pascuitti representing NASA, and F. Raposa representing HSED. The first draft of the Final Project Report for the Phase I program was transmitted to NASA for approval at this meeting. A complete review of the Phase I program was presented during this conference.

A conference was held at NASA Goddard on March 3, 1966. In attendance were Messrs. F. Yagerhofer and E Pascuitti representing NASA and E. Trifari and F. Raposa representing HSED. Possible supplemental effort and schedule extension was discussed for application of the unified power stage concept for both the booster and chopper regulator-converters. The Final Project Report for the Phase I program as reviewed in detail and it was agreed that the changes, corrections and inclusions recommended by Mr. Pascuitti be incorporated into the final draft of this report.

A conference was held at HSED on April 4-5, 1966. In attendance were Messrs. E. Pascuitti representing NASA and F. Raposa and R. Seaver representing HSED. The purpose of this meeting was to obtain definition of satellite DC source characteristics so that the input filter configuration on the regulator-converters could be firmed up. Mr. Pascuitti presented two basic satellite power source systems:

1. Solar array/shunt regulator in parallel with batteries.
2. Solar array with an optimum power transfer network paralleled by batteries.

It was agreed that only the first system should be considered at this time. The static characteristics of this system were made available and it was agreed that testing at NASA Goddard be made with actual booster breadboards to obtain the dynamic characteristics of this system.

A conference was held at NASA Goddard on May 2-3, 1966. In attendance were Messrs. E. Pascuitti and J. Paulkovich representing NASA; Messrs. F. Raposa and R. Seaver representing HSED. The purpose of this meeting was to determine the DC source characteristics of a typical satellite DC power source, and to define the input filter configuration for the booster converters using the above DC satellite source. Output impedance data was obtained from a solar array simulator/shunt regulator-battery system under varying states of operation. Input filter configurations were defined for the 25 watt booster regulator.

A conference was held at NASA Goddard on July 20, 1966. In attendance was Mrs. E. Pascuitti representing NASA, and Mr. F. Raposa representing HSED. The revised circuit protection scheme providing both overload and short circuit protection was covered. It was agreed that this revised circuit be used at the 10 watt and 25 watt levels, and that the original circuit protection scheme presented in the sixth quarterly report be used at the 50 watt and 100 watt levels.

A conference was held at NASA Goddard on December 20, 1966. In attendance were Messrs. F. Yagerhofer and E. Pascuitti representing NASA, and Mr. F. Raposa representing HSED. A financial and technical review of the complete program was made. The effort remaining to complete the program was agreed to as:

1. Complete all design and development effort on the booster regulator converters.
2. Development of the Phase II chopper regulator converters would be limited to open loop controlled breadboards.
3. Final technical report would be a comprehensive report summarizing the results of the entire program effort.

8.0 NEW TECHNOLOGY

Single Ended Self-Stabilizing Chopper

The subject program has a requirement for extremely tight dynamic voltage regulation. This requirement has dictated the need to develop power conversion circuits possessing automatic compensation against input line variations. The circuit presented here achieves the self-stabilization requirement through the utilization of the constant volt second characteristic of the drive transformer.

The single ended self-stabilizing chopper, Fig. 22 consists of: A chopper transistor Q1; a driver stage consisting of diodes D1, D2, and D3, transistors Q2 and Q3, resistors R1, R2, and R3, and saturating transformer T1; and an output filter stage consisting of inductor L1, capacitor C1, and diode D4.

Transistor Q1 is driven through diodes D2 and D3 at a switching frequency of twice the drive frequency. The switching action of Q1 produces a unidirectional pulsating voltage at the input of the filter which averages this pulsating voltage to a DC level. The magnitude of the output voltage V_o is determined by $V_o = V_i t/T$ where t/T is termed the duty cycle of the main chopper switch.

The self-stabilizing scheme used in this circuit makes use of the constant volt second product of transformer T1 . Transformer T1 is capable of supporting a voltage V_i for a time t seconds; hence, if V_i increases t must decrease to maintain the constant volt second product. Thus, the on time of the main power switch Q1 is made proportional to the input voltage V_i, and automatic compensation against input line variations can be achieved.

Auxiliary means of initiating each half cycle is required; this is accomplished with an external gate pulse input fed in through diode D1 and synchronized to the drive signal for transistors Q3 and Q2. The gate pulse input has a magnitude and time duration sufficiently large to momentarily forward bias the main power switch Q1. Momentarily forward biasing transistor Q1 allows the voltage V_i to be impressed across transformer T1. Transistor Q1 is then driven by either transistor Q2 or Q3 through the resistor diode combination of either R1, D2, or R2, D3.

After a given number of volt-seconds, determined by transformer T1, saturation of transformer T1 occurs. This causes the drive to transistor Q1 to be extinguished, thus turning Q1 off. Resistor R3 provides degeneration feedback to the circuit to insure fast turn off recovery after transformer T1 has saturated.

The circuit described above provides automatic regulation of the output voltage against input line variations only. Regulation against load variations is easily accomplished by varying the frequency of the square wave drive source for transistors Q2 and Q3. This results in the duty cycle t/T having the t a function of input voltage and the T a function of load.

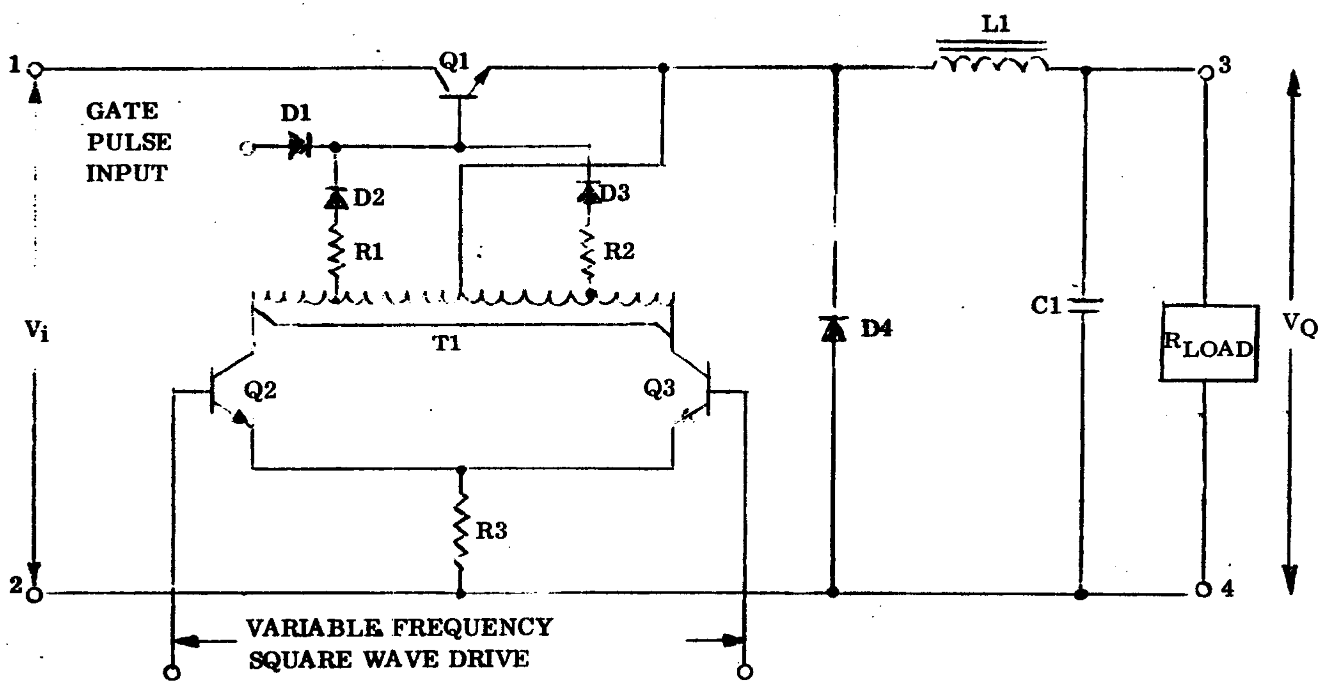


FIGURE 22 SINGLE ENDED SELF-STABILIZING CHOPPER

Converter Protection Circuit

One of the requirements of the regulator converters being developed in the subject program is short circuit protection of the converters. The booster converters being developed in this program have no inherent means of providing short circuit protection. The circuit presented in Fig. 23 provides a means of short circuit protection by isolating the output terminals of the converter from the short circuit load whenever this condition occurs.

The output terminals of the converter are connected to terminals 1 and 2; the load is connected to terminals 3 and 4. When voltage is first applied across terminals 1 and 2, transistor Q1 is in a non-conducting state. A leakage is set just high enough to allow enough bias to be developed across resistor R3 to turn transistor Q3 on. Transistor Q3 then turns on transistor Q2 which then turns on transistor Q1. Voltage now appears across terminals 3 and 4, transistor Q1 is driven into saturation; normal operation now occurs.

When a short circuit is applied to terminals 3 and 4, transistor Q3 is forced into a non-conducting state since no voltage can be developed across the resistor combination of R2 and R3. With transistor Q3 non-conducting, transistors Q2 and Q1 are turned off. Thus, with transistor Q1 turned off, the short circuit condition is prevented from being applied across terminals 1 and 2, and isolation from the short circuit is obtained. When the short circuit is removed, the circuit automatically returns to the saturated on state through the starting process described above.

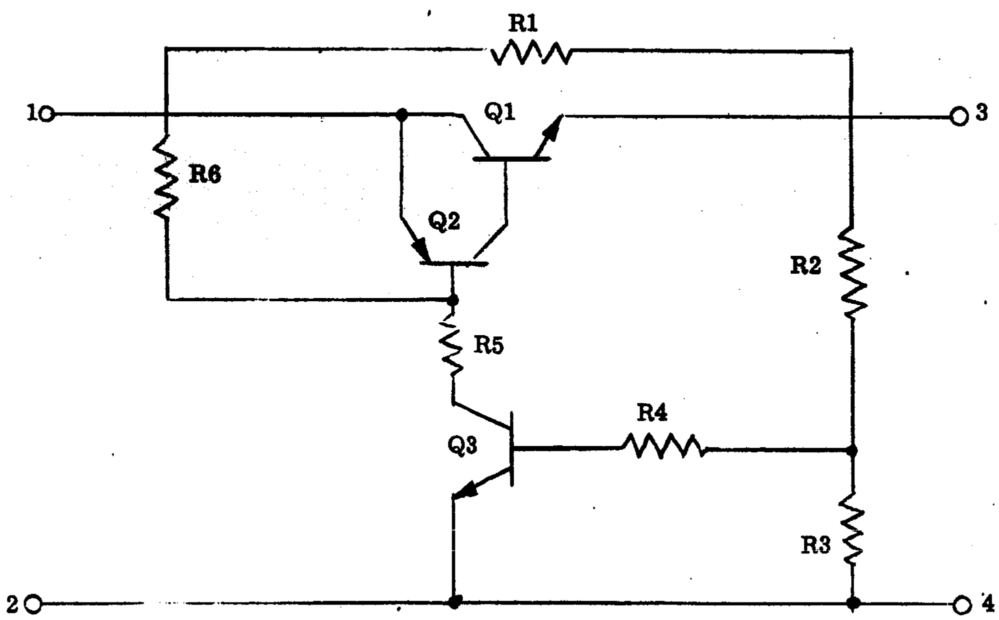


FIGURE 23 CONVERTER PROTECTION CIRCUIT

Appendix I

Output Impedance Tests of a

Typical Satellite DC Power Source

Output impedance measurements were obtained for the simulated satellite DC power source described in section 4.4. The test schematic is shown in figure II-1. The source to be measured is loaded as desired. Capacitor C blocks DC current from the sine wave generator, and is chosen large enough to be a small impedance over the frequency range to be tested. The sine wave generator is set to the desired frequency and this AC signal passes through R, C, and the source under test; (it is assumed that the load impedance is much greater than the source impedance). Thus, the current through R equals the current through the source, and the output impedance can be determined as:

$$Z_O = \frac{V}{T}$$

but

$$I = \frac{V_R}{R}$$

giving

$$Z_O = \frac{V_s}{V_R} \times R$$

where all voltages are the peak to peak components

Output impedance data was obtained for the following conditions under varying loads:

1. Solar array simulator/shunt regulator with fully charged batteries floating across the line.
2. Solar array simulator/shunt regulator de-energized. Drawing power from battery source.
3. Solar array simulator/shunt regulator only.
4. Solar array simulator/shunt regulator de-energized. Battery source operating near full discharge.

The data for the different conditions above is shown in tables II-1 through II-4 and figures II-2 through II-5.

The characteristics of the output impedance are caused by several interrelated factors including amplifier gain, output circuit capacitance, internal circuit resistance, and output circuit inductance. The amplifier gain is most important at low frequencies. The output capacitance is effective mainly in the mid-frequency band; however, there is usually considerable overlap with the amplifier gain frequency characteristic. At high frequencies the output circuit inductance plays the major role in determining the output impedance.

Figure II-2 shows the output impedance characteristic for the complete satellite simulated DC power source with the battery pack at full charge. In the frequency range from 1 KC to 3 KC is shown the combined effects of the shunt regulator amplifier gain frequency characteristic and output circuit capacitance. The output circuit capacitance is shown to be predominant between 3 KC and 30 KC. Above 30 KC the output circuit inductance is the dominating factor.

Figure II-3 shows the output impedance characteristic of the fully charged battery pack. The battery capacitance is predominant in the frequency range between 1 KC and 10 KC; this is particularly evident at no load. Above 30 KC the output circuit inductance is the dominating factor.

Figure II-4 shows the output impedance characteristic of the solar array simulator and shunt regulator; the shunt regulator is essentially a multi-staged emitter follower circuit. In the frequency range of 1 KC to 10 KC is shown the effect of the amplifier's gain frequency characteristic. A small capacitance effect is shown in the frequency range between 10 KC and 30 KC. Above 30 KC the output circuit inductance is the dominating factor.

Figure II-5 shows the output impedance characteristic of the battery pack when nearly fully discharged. The battery pack exhibits essentially a resistance effect for frequencies up to 30 KC. Above 30 KC the output circuit inductance is the dominating factor.

TABLE I-1

Solar Array Simulator/Shunt Regulator activated.
Battery floating across output at full charge
V_O = 19.6 VDC

Frequency	Load Condition								
	$I_L = 0$, I_{SR} = 2 ADC			I_L = 0.4 ADC, I_{SR} = 1.6 ADC			I_L = 1.8 ADC, I_{SR} = 0.2 ADC		
f KC	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω
1	.04	.01	.26	.04	.01	.26	.04	.03	.78
2		.03	.78		.03	.78		.07	1.8
2.6								.12	3.1
3.3		.15	3.9		.15	3.9			
4		.10	2.6		.08	2.1		.06	1.6
10		.015	.39		.02	.52		.015	.39
15		.01	.26		.01	.26		.01	.26
20		.01	.26		.01	.26		.01	.26
30		.015	.39		.015	.39		.015	.39
60		.03	.78		.03	.78		.03	.78
100		.05	1.3		.05	1.3		.05	1.3

$$Z_O = \frac{V_1}{V_R} \times R \qquad R = 1.04\ \Omega$$

TABLE I-2

Solar Array Simulator/Shunt Regulator de-energized. Drawing power from battery source

Frequency	Load Condition								
	$I_L = 0$ $V_O = 18.7$ VDC			$I_L = 0.4$ ADC $V_O = 16.2$ VDC			$I_L = 1.7$ ADC $V_O = 14.8$ VDC		
f KC	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω
1	.04	.13	3.4	.04	.05	1.3	.04	.02	.52
2	↓	.08	2.1	↓	.05	1.3	↓	.02	.52
4	↓	.04	1.0	↓	.04	1.0	↓	.02	.52
10	↓	.015	.39	↓	.02	.52	↓	.01	.26
15	↓	.01	.26	↓	.01	.26	↓	.01	.26
20	↓	.01	.26	↓	.01	.26	↓	.01	.26
30	↓	.015	.39	↓	.02	.52	↓	.015	.39
60	↓	.04	1.0	↓	.03	.78	↓	.03	.78
100	↓	.06	1.6	↓	.06	1.6	↓	.05	1.3

$$Z_O = \frac{V_S}{V_R} \times R \qquad R = 1.04\ \Omega$$

TABLE I-3 Solar Array Simulator/Shunt Regulator Activated. Battery Disconnected

V_O = 19.6 VDC

FREQUENCY	LOAD CONDITION					
	$I_L = 0$, I_{SR} = 2 ADC			I_L = 1.8 ADC, I_{SR} = 0.2 ADC		
f KC	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω
1	0.4	.015	.39	.04	.025	.65
2		.03	.78		.05	1.3
4		.07	1.8		.15	3.9
10		.22	5.7		.17	4.4
15		.17	4.4		.14	3.6
20		.15	3.9		.125	3.2
30		.13	3.4		.125	3.2
60		.15	3.9		.13	3.4
100		.19	4.9		.16	4.2

$$Z_O = \frac{V_S}{V_R} \times R \qquad R = 1.04\ \Omega$$

TABLE I-4

Solar Array Simulator/Shunt Regulator de-energized. Battery Source Operating Near Full Discharge.

FREQUENCY	LOAD CONDITION					
	$I_L = 0$, $V_O = 11.2$ VDC			$I_L = 1.5$ ADC, $V_O = 11.9$ VDC		
f KC	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω	V_R V_{p-p}	V_S V_{p-p}	Z_O Ω
1	.04	<.01	<.26	.04	.03	.78
2		<.01	<.26		.01	.26
4		.01	.26		.01	.26
10		.012	.32		.01	.26
15		.012	.32		.015	.39
20		.017	.44		.015	.39
30		.025	.65		.02	.52
60		.05	1.3		.05	1.3
100		.08	2.1		.07	1.8

$$Z_O = \frac{V_S}{V_R} \times R \qquad R = 1.04\,\Omega$$

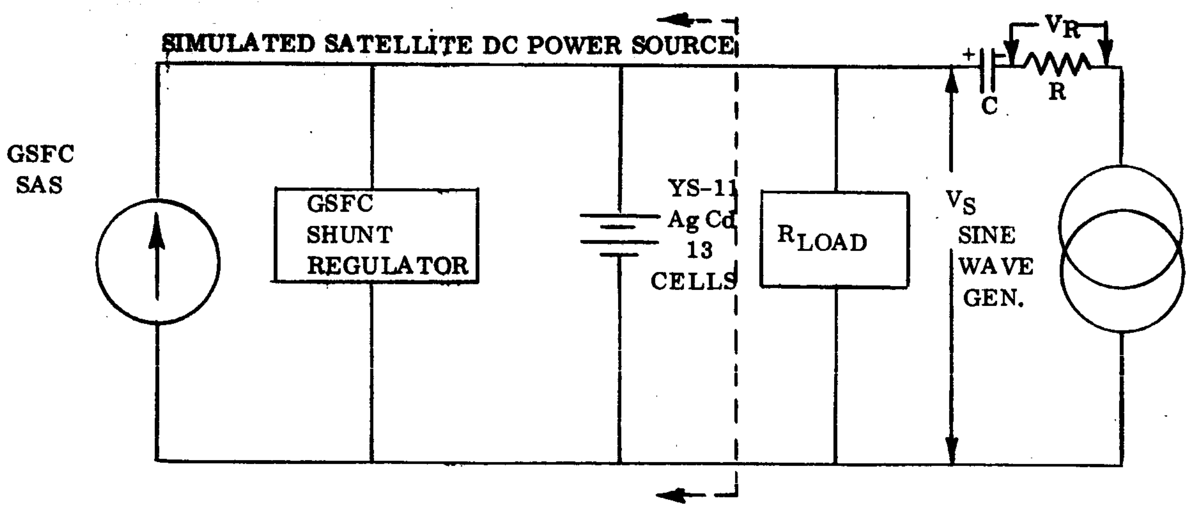


FIGURE I-1 TEST SCHEMATIC FOR OUTPUT IMPEDANCE TEST

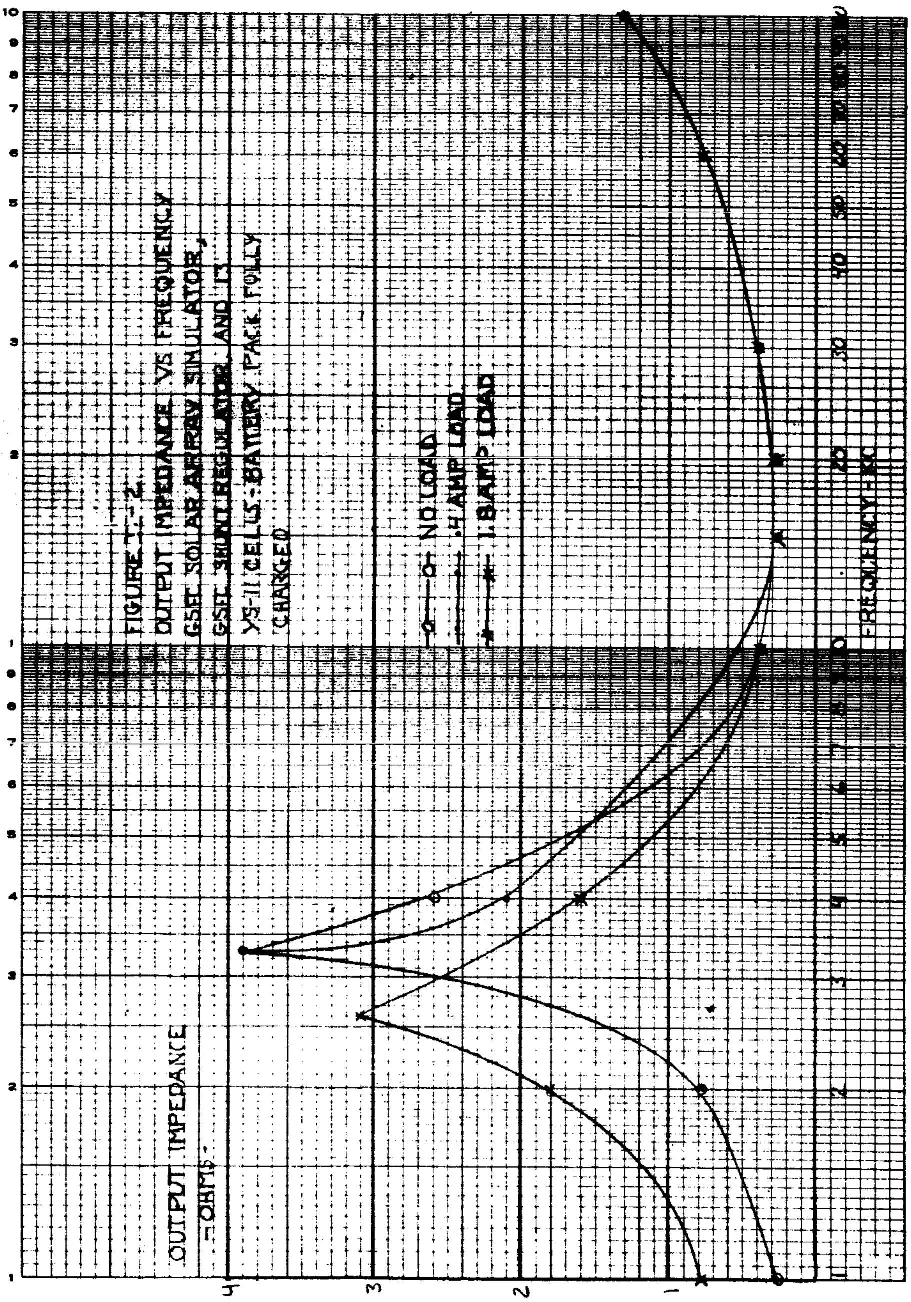
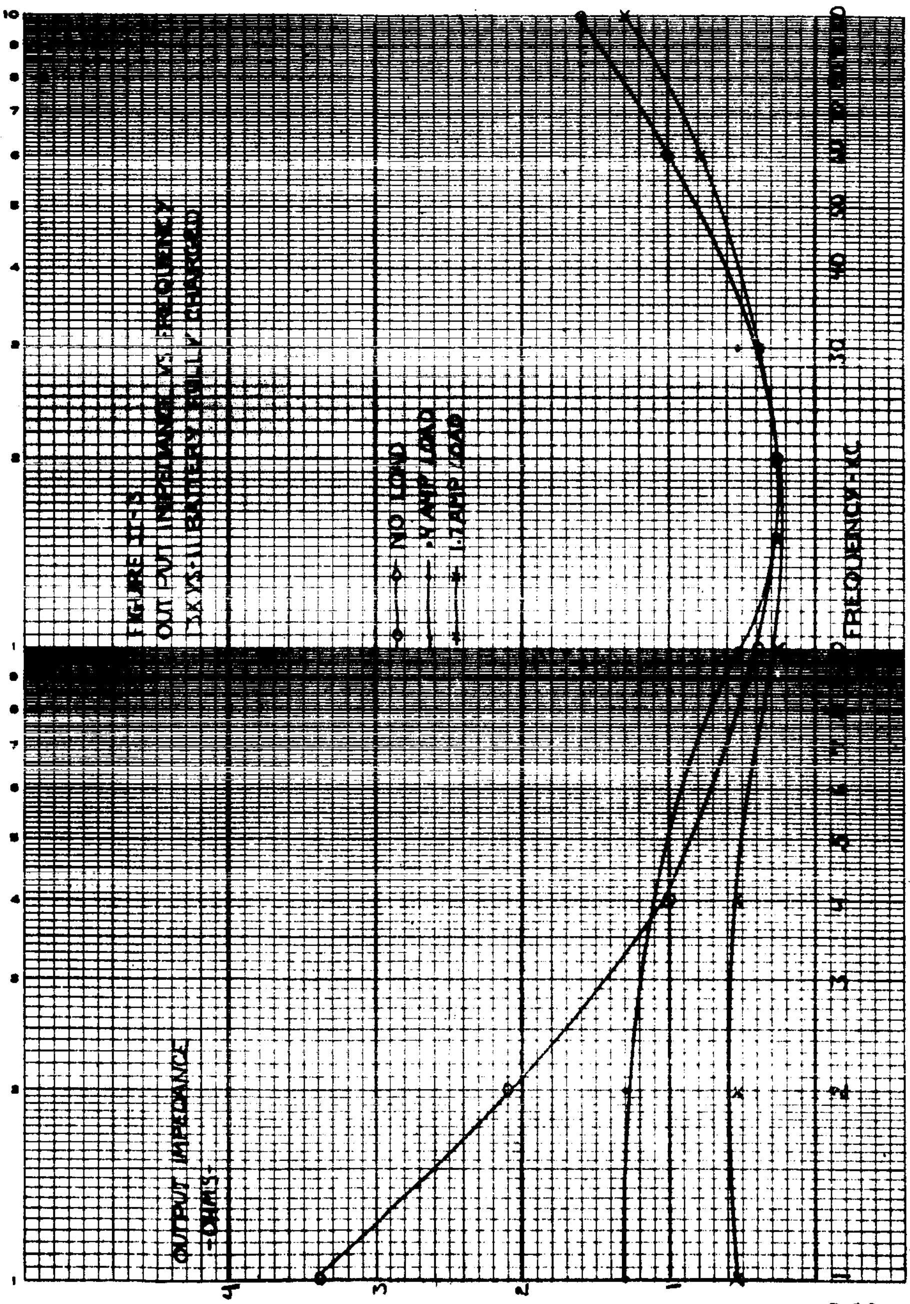


FIGURE I-2
OUTPUT IMPEDANCE VS FREQUENCY
GSFC SOLAR ARRAY SIMULATOR,
GSFC SHUNT REGULATOR AND 13
YS-11 CELLS - BATTERY PACK FULLY
CHARGED
NO LOAD
.4 AMP LOAD
1.8 AMP LOAD
OUTPUT IMPEDANCE - OHMS
FREQUENCY - KC
1
2
3
4


OUT PUT IMPEDANCE VS FREQUENCY
NO LOAD
OUTPUT IMPEDANCE
-OHMS-
FREQUENCY-KC

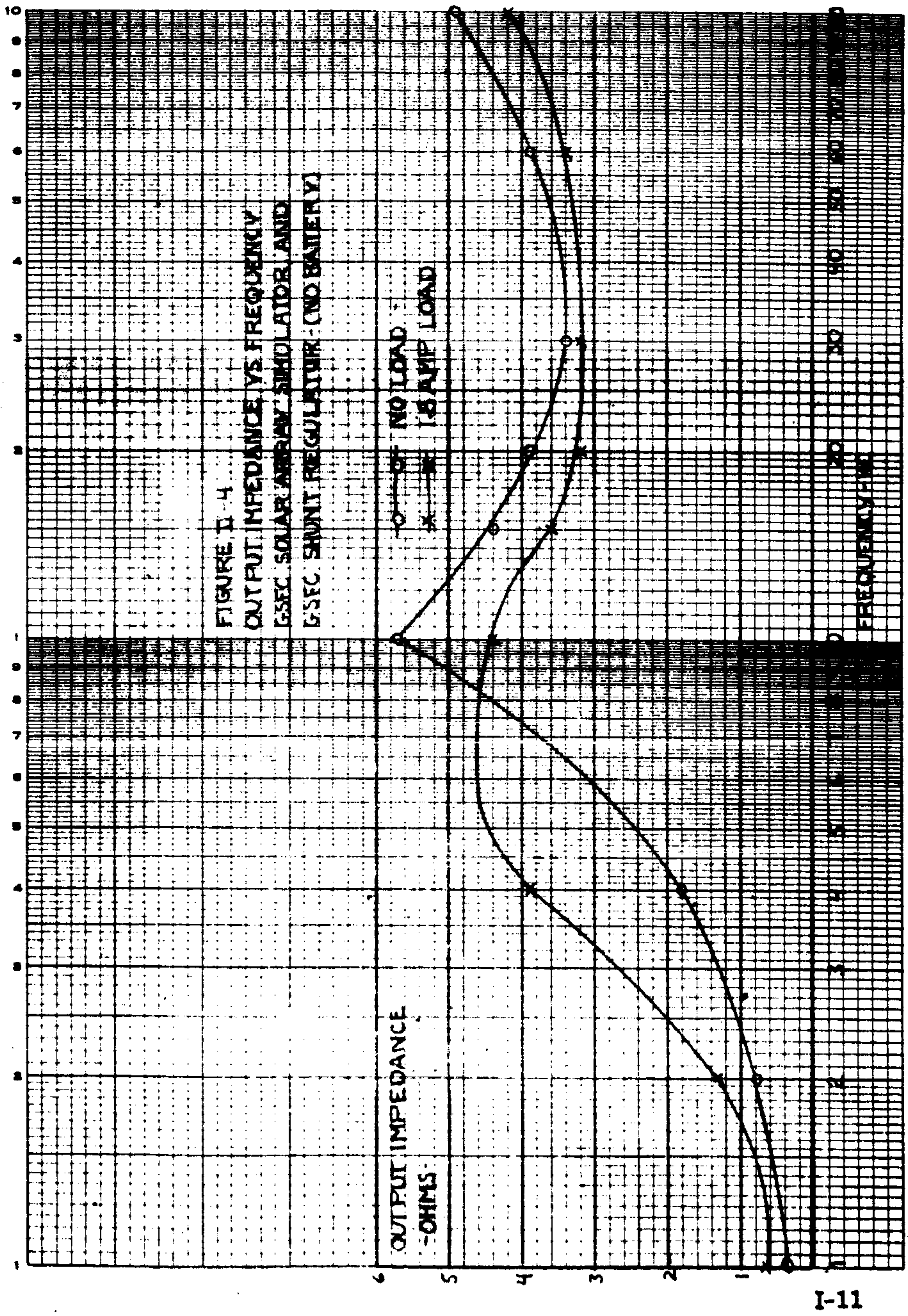


FIGURE II-4
OUTPUT IMPEDANCE VS FREQUENCY
GSFC SOLAR ARRAY SIMULATOR AND
GSFC SHUNT REGULATOR (NO BATTERY)
NO LOAD
1.8 AMP LOAD
OUTPUT IMPEDANCE -OHMS
FREQUENCY-HZ

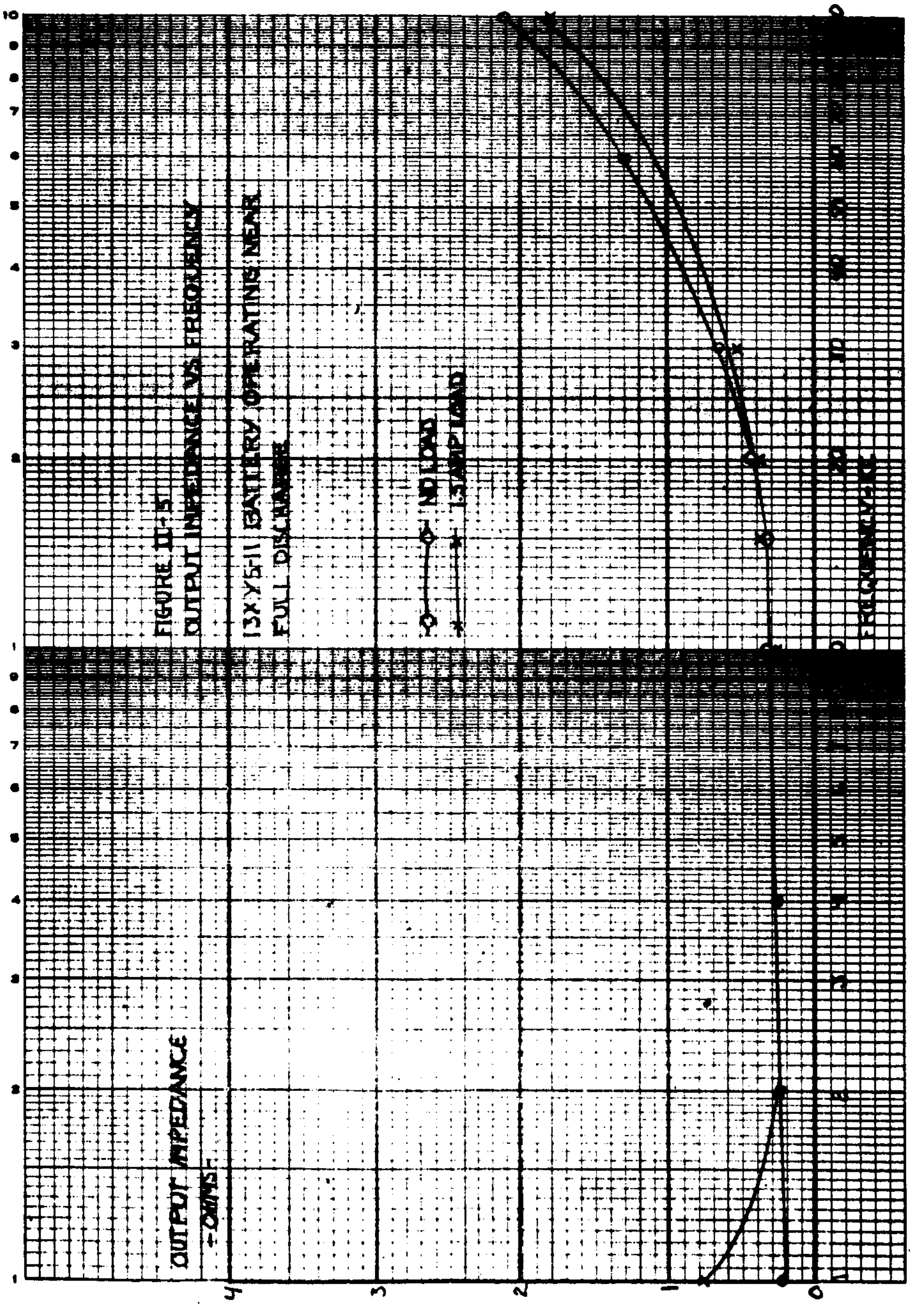


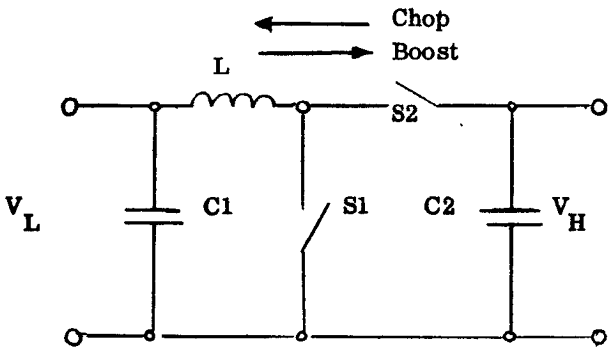
FIGURE II-5
OUTPUT IMPEDANCE VS FREQUENCY
13 X Y5-11 BATTERY OPERATING NEAR
FULL DISCHARGE
NO LOAD
1.5 AMP LOAD
OUTPUT IMPEDANCE - OHMS
FREQUENCY-KC

APPENDIX II

UNIFIED POWER STAGE CONCEPT

Unified Power Stage Concept

The circuit shown in Figure I-1 can act as a booster or chopper of DC voltage depending upon the direction of power flow within the circuit.



S1 is closed when S2 is open, S1 is open when S2 is closed; both S1 and S2 are bidirectional switches

Figure I-1 - Unified Power Stage Concept.

For boosting action, the input voltage is supplied to the V_L terminals, and a voltage higher than V_L is produced at V_H. In operation, switch S1 closes with switch S2 open, and current builds up linearly through inductor L. After a given interval, switch S1 opens, and switch S2 closes. This adds the voltage induced in the inductor L to the source voltage creating an output voltage higher than the input voltage. During the next half cycle switch S2 opens and S1 closes, so that inductor L is charging up, and capacitor C2 is discharging into the load. It can be shown that the boost output is given by:

$$V_o = \frac{V_L}{1-\theta}$$ where θ is the conduction angle of switch S1

For chopping action the source voltage is supplied to the V_H terminals, and the output is taken at V_L. In operation, switch S2 is closed and switch S1 is open; as with the booster, the current builds up in choke L. After a given interval S2 opens and S1 closes. Now the voltage induced in choke L is directly across the load. It can be shown that the chopped output is given by:

$V_o = V_i \; \emptyset$ where $\emptyset$ is the conduction angle of switch S2.

Note that in the above discussion, the current flow through switches S1 and S2 must be bidirectional for the given circuit to provide either boosting or chopping action.

For practical operation, switches S1 and S2 must be replaced with semiconductors which are unidirectional devices. For chopper action, switch S1 is replaced by a diode and S2 is replaced by a transistor as shown in Figure I-2.

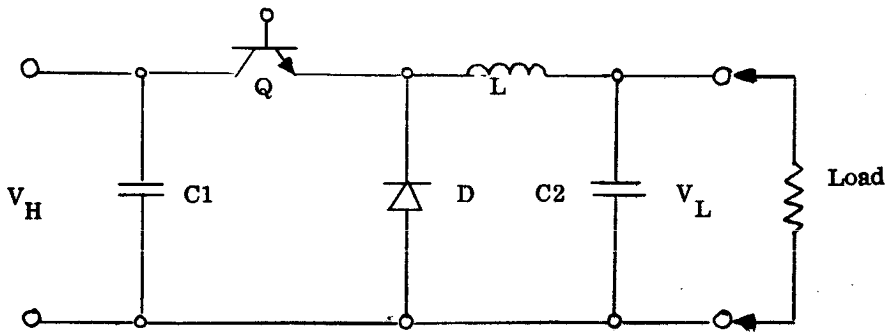


Figure I-2 Chopper Power Stage

Transistor Q is switched by external circuitry, and diode D is switched by the polarity reversals across the inductor L. With transistor Q on, diode D is back biased by the source voltage; when transistor Q is off, diode D is forward biased by the induced voltage across inductor L.

For booster action, switch S1 is replaced by a transistor, and switch S2 is replaced by a diode as shown in Figure I-3.

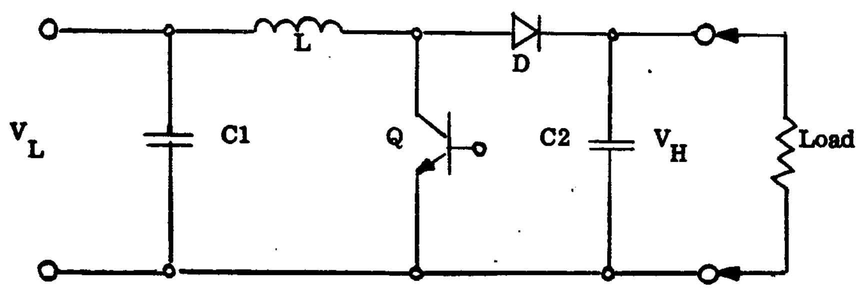
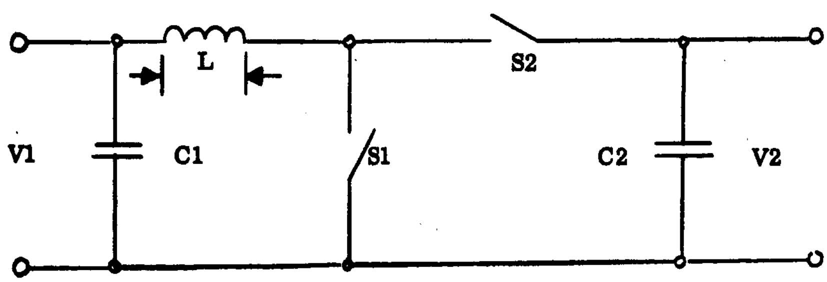


Figure I-3 Booster Power Stage

Transistor Q is switched on and off by external circuitry and diode D is switched by the changing bias voltage caused by the switching action of transistor Q. With transistor Q on, D is back-biased by the output voltage; when transistor Q is off, diode D is forward biased by the induced voltage in choke L and the supply voltage.

<u>Derivation of Chopper-Booster Output Voltage</u>



Conditions:

t_1 and E_1 are the time and voltage across L when S1 is conducting.

t_2 and E_2 are the time and voltage across L when S2 is conducting.

Using the basic equation for induced voltage,

1) $E = \frac{L \Delta i}{\Delta t}$ or $E \Delta t = L \Delta i$ Because the total volt-second product across inductor L must equal zero,

2) $E_1 \Delta t_1 = E_2 \Delta t_2 = L \Delta i_1 = L \Delta i_2$

3) During Δt_1, $V_1 = E_1$ or $E_1 = V_1$

4) During Δt_2, $V_2 = V_1 + E_2$ or, $E_2 = V_2 - V_1$

Substituting equations 3 and 4 into equation 2,

5) $V_1 \Delta t_1 = (V_2 - V_1) \Delta t_2$ or $V_1 (\Delta t_1 + \Delta t_2) = V_2 \Delta t_2$

defining T as the total period $\Delta t_1 + \Delta t_2$

$$V_2 = \frac{V_1 T}{\Delta t_2}$$

This equation is the general form for either the booster or the chopper; for booster action V_2 is the output voltage and V_1 is the input voltage; therefore:

$V_o = V_i \frac{T}{\Delta t_2}$ and $\Delta t_2 = T - \Delta t_1$ so,

$$V_{OUT} = V_{IN} \frac{T}{T - \Delta t_1} = \frac{V_{IN}\ 1}{1 - \frac{\Delta t_1}{T}} = V_{IN} \frac{1}{1 - \theta}$$

where θ is the conduction angle of switch S1.

For chopping action, V_2 is the input voltage and V_1 is the output voltage, so:

$$V_i = Vo \frac{T}{t_2} \quad \text{or } Vo = Vi \frac{t_2}{T} = Vi\ \phi$$

where ϕ is the conduction angle of switch S2.

APPENDIX III

Breadboard Test Data
Booster Regulator Converters

BOOSTER PERFORMANCE CHARACTERISTICS

The following tests were run on the Phase II boosters to determine their performance characteristics:

1. No load losses
2. Efficiency
3. Static regulation
4. Output voltage ripple
5. Input current ripple
6. Dynamic regulation
7. 40 hour extended operation
8. Short circuit protection

The no load losses test was run with a digital voltmeter directly at the input of the booster and an ammeter between the voltmeter and the power source. Power was calculated as the volt-ampere product.

The efficiency was run with a digital voltmeter directly at the input and output of the booster and ammeters between the input voltmeter and the power source and between the output voltmeter and the load. Efficiency was calculated as $(V_{out} I_{out} / V_{in} I_{in}) \times 100$.

Static regulation was measured with a digital voltmeter directly at the input and output of the booster with the booster in a temperature chamber.

Output voltage ripple was measured on a (561A) Tektronix oscilloscope across the output. Only ripple below 1 mc was recorded.

Input current ripple was measured with a (561A) Tektronix oscilloscope across a .28 ohm resistor for the 10 and 25 watt booster and a .105 ohm resistor for the 50 and 100 watt boosters in series with the input supply line. Dynamic regulation was run by switching loads and input voltages with the circuit shown below and was measured on a (564) Tektronix storage scope.

1 Resistor, wire wound - 5 watt, .105 ohm

1 Resistor, 2 watt, 1 ohm

1 Capacitor 20,000 uf

1 Capacitor 1000 μf

Temperature Chamber, Statham TC 2B

1 Capacitor 80 μf

Load Boards 10, 25, 50, 100 watt

1 Diode 10 amp 1N1188

Overload and short circuit protection was tested in all boosters by overloading and short circuiting the low power and high power boards respectively and noting whether or not the input current decreased to a safe value. Because of the nature of this test, no tables or graphs are presented; all units were satisfactorily protected.

BOOSTER DATA ANALYSIS

I. No load losses: No load losses are primarily a function of the input voltage as is shown by the fact that (neglecting protection circuits) the 10, 25, and 50 watt boosters have almost identical no load loss characteristics, varying from 1.5 watts at low line to 2 watts at high line. Because the 100 watt booster operates over a higher input voltage range, the no load losses are proportionally higher; added to this, the 100 watt unit requires a bleeder load, because of the small inductance in its flyback choke. The 100 watt booster no load losses vary from 5.6 to 6.0 watts, and 3 watts of this is in the bleeder.

Addition of the protection circuits increases the no load losses substantially. The overload protection circuit adds about .6 watts loss to the 10 and 25 watt boosters, and the short circuit protection adds about 1.3 watts to the 50 and 100 watt no load losses.

II. Efficiency

Efficiency measurements were taken on all the boosters, with an without protection circuits, at 1/4, 1/2, 3/4 and full load and over the input voltage range. The data shows a general increase of efficiency with input voltage except at light loads where control losses become predominant. As has been known, these losses increase with input voltage thus reducing efficiency. The peak efficiencies for the 10, 25, 50, and 100 watt boards without protection are 82.3%, 88.3%, 91.0%, and 92.6% respectively; the protected units have efficiencies of 74.6%, 80.4%, 84.5%, and 88.6% indicating that the protection devices are between 90% and 96% efficient depending on the power level and type of protection desired.

III. Static Regulation

Output voltage was measured at -20°C, room temprature, and +70°C for no load, 1/4 load, 1/2 load, 3/4 load, and full load over the specified input voltage range for units with and without protection devices. The output voltages are well within the specified limits, but the data indicates more drift at low temperature than high; that is partly because the regulators were trimmed to prevent saturation at high temperature which resulted in operation near cut-off at low temperature. When operated without protection the 10 watt board varied from 22.05 to 21.89 over line load and ambient, while in the protected mode it varied from 22.08 to 21.81. In both cases, the output was set to 22.00 at room temperature 15 volts input and 1/2 load. The regulation of all the boosters is similar and within specified limits.

IV. Output Voltage Ripple:

Output ripple was measured at low line, mid line, and high line at no load and full load. The ripple can be divided into two frequency ranges: Below 1 mc and above 1 mc. Because the breadboards are open and EMI shielding and filtering are impractical, only the components below 1 mc are recorded. This portion of the ripple is a 30 KC sinusoid and is within specified limits. The ripple decreases as the input voltage increases as would be expected from the previously presented equation:

$$V_{p-p} = \frac{E_{out} - E_{in}}{f R_L C}$$

where f is the frequency of operation, C is the output capacitor and R_L is the load.

V. Input Current Ripple:

Input ripple was measured at low line, mid line, and high line at no load and full load. The ripple can be divided into two frequency ranges: Below 1 MC, for the reasons described above. The ripple current is theoretically independent of load and should be a maximum when the input voltage equals one half of the output voltage. While this holds true for no load, at full load the saturating chokes used exhibit a decreased inductance which adds another variable to the equation:

$$\Delta i = \frac{Ein\ (Eout - Ein)}{fL\ Eout}$$

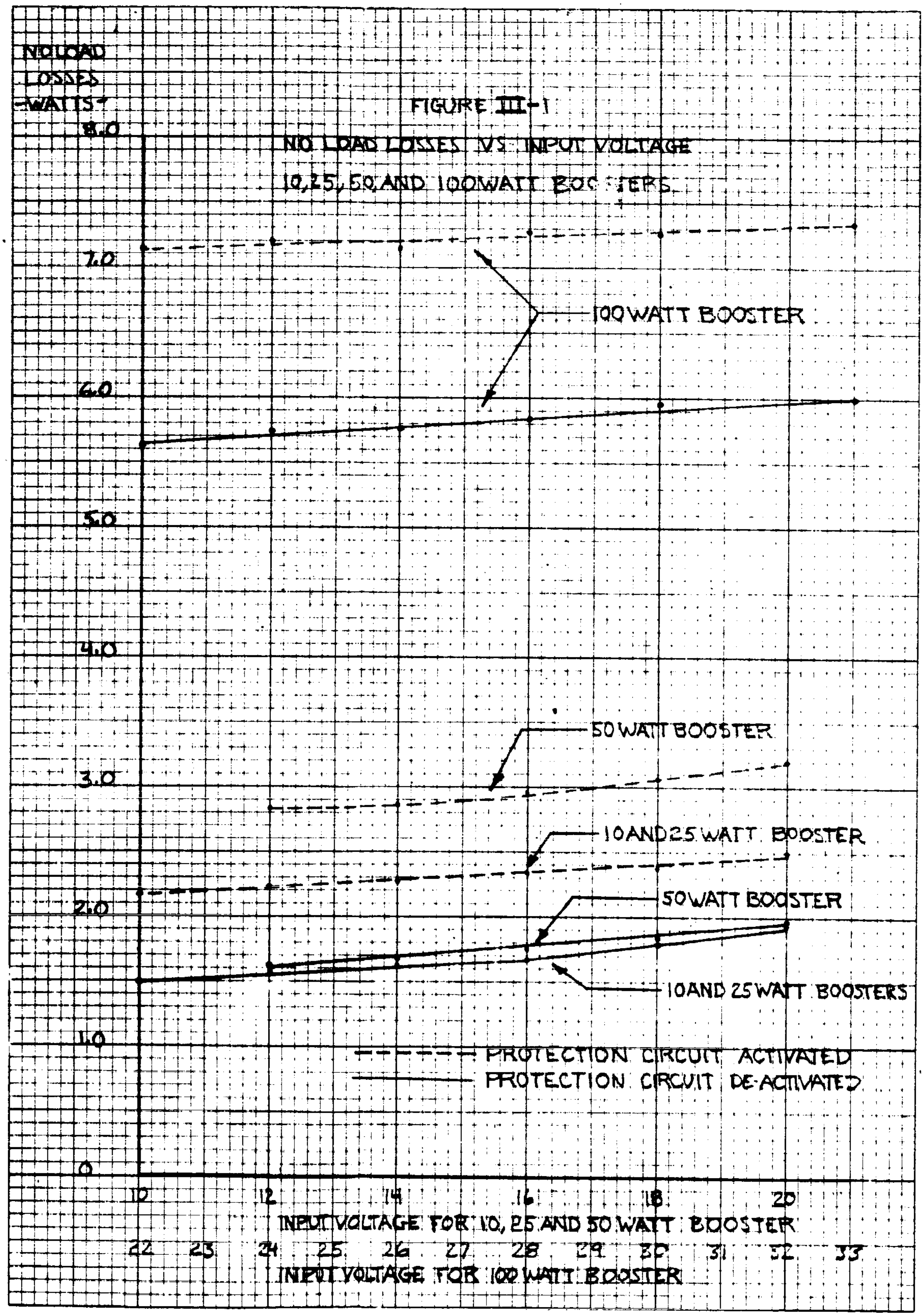
As a result of this decrease in inductance, the full load ripple is generally greater than at no load. The only exception to this appears at the 10 watt level, where the high frequency radiation probably overloads the oscilloscope amplifier causing distortion of the wave shape, however, all ripple is within the specified limits.

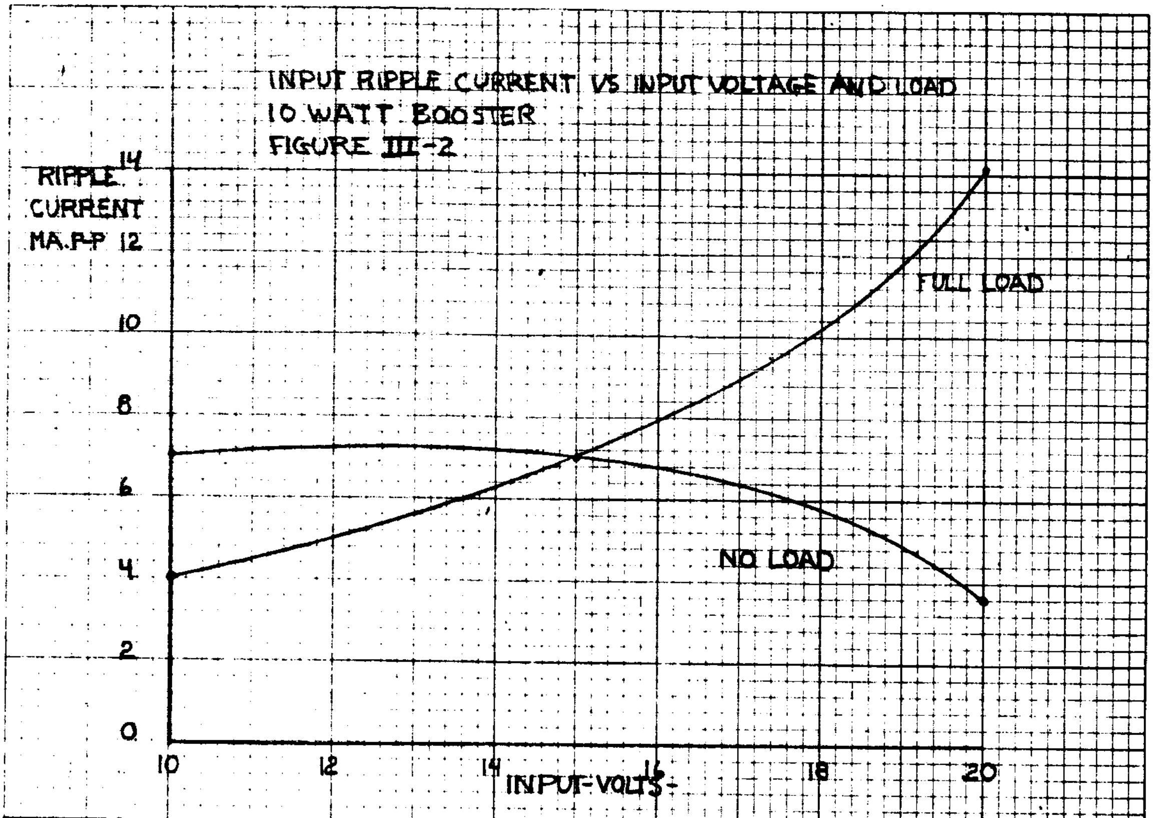
VI. Dynamic Response:

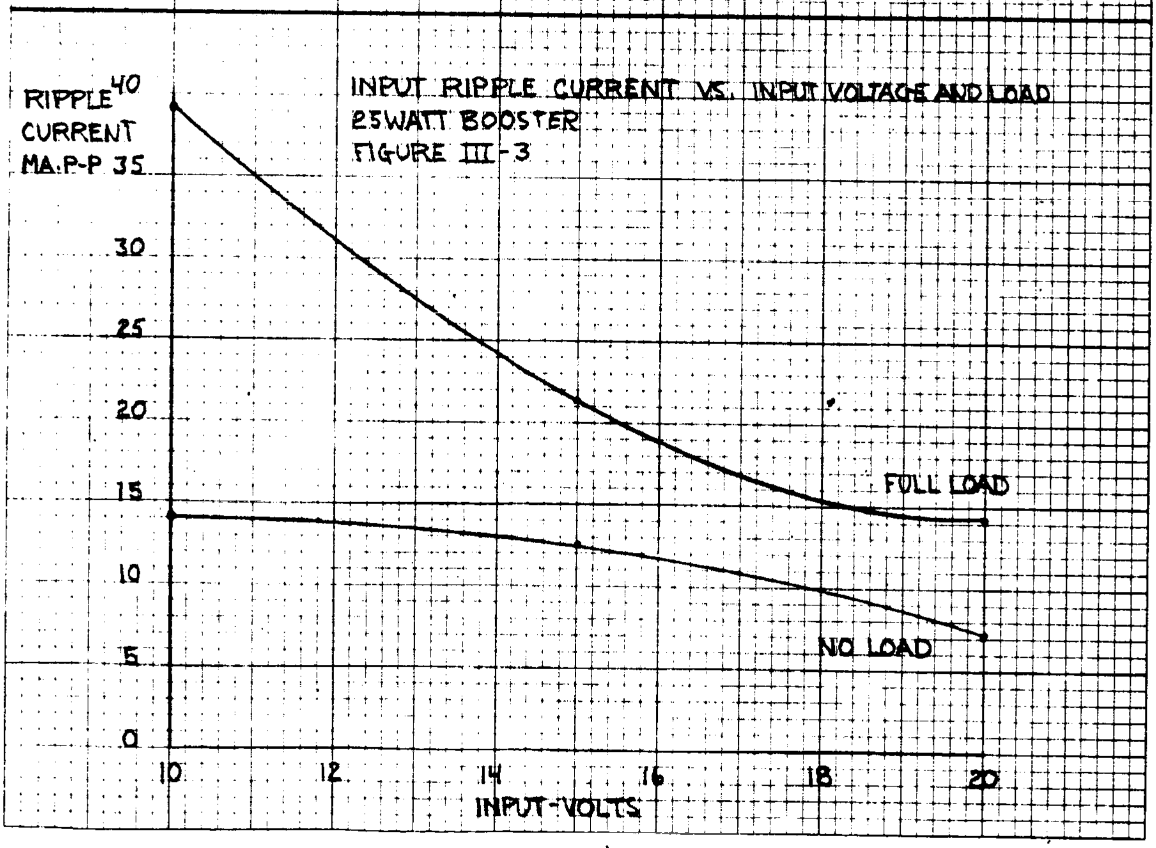
Dynamic response was tested by switching the input voltage from low line to high line and high line to low line at full load and no load, then the load was switched from 3/4 to full load and full load to 3/4 at high line and low line. The results are shown in Table III-1 and dynamic response photographs. For the most part, the recovery times were well within specifications but the maximum voltage excursions were greater than the specified ± 2% limit for many cases. These results are due to designs based on the results of the tests recorded in the 7th quarterly reports and are a compromise between maximum excursion, recovery time, static regulation and stability.

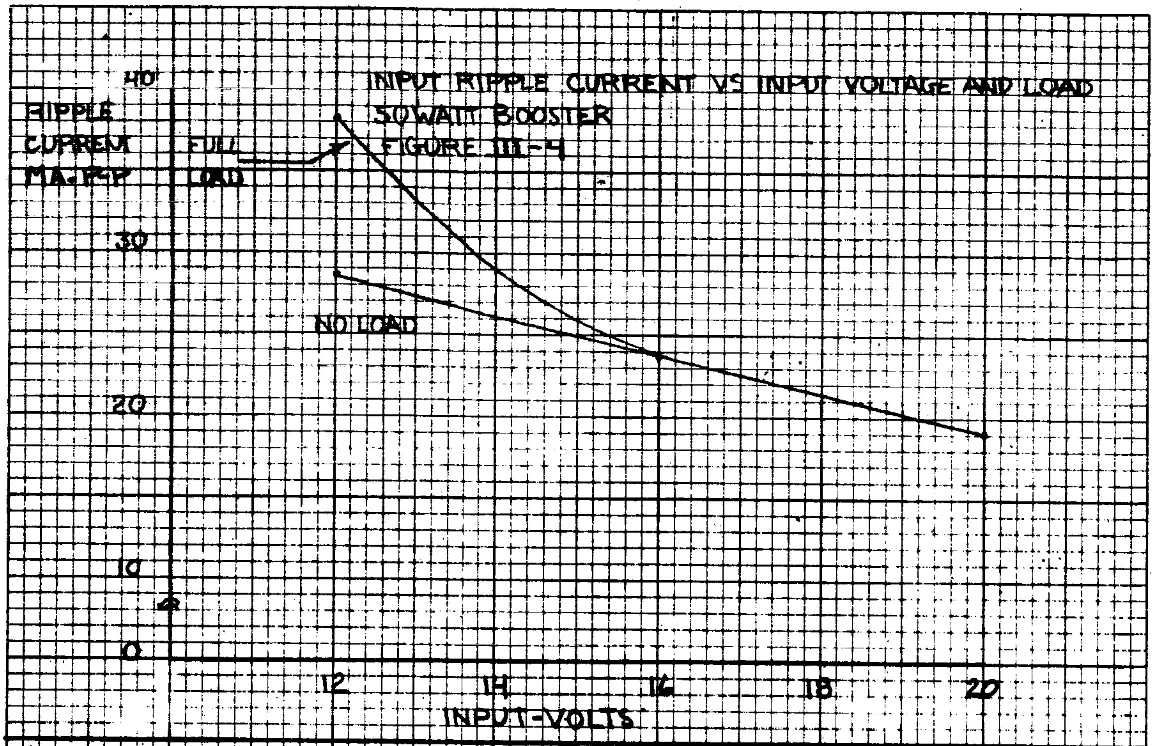
Table III-1 Dynamic Response of Booster Regulator Converters

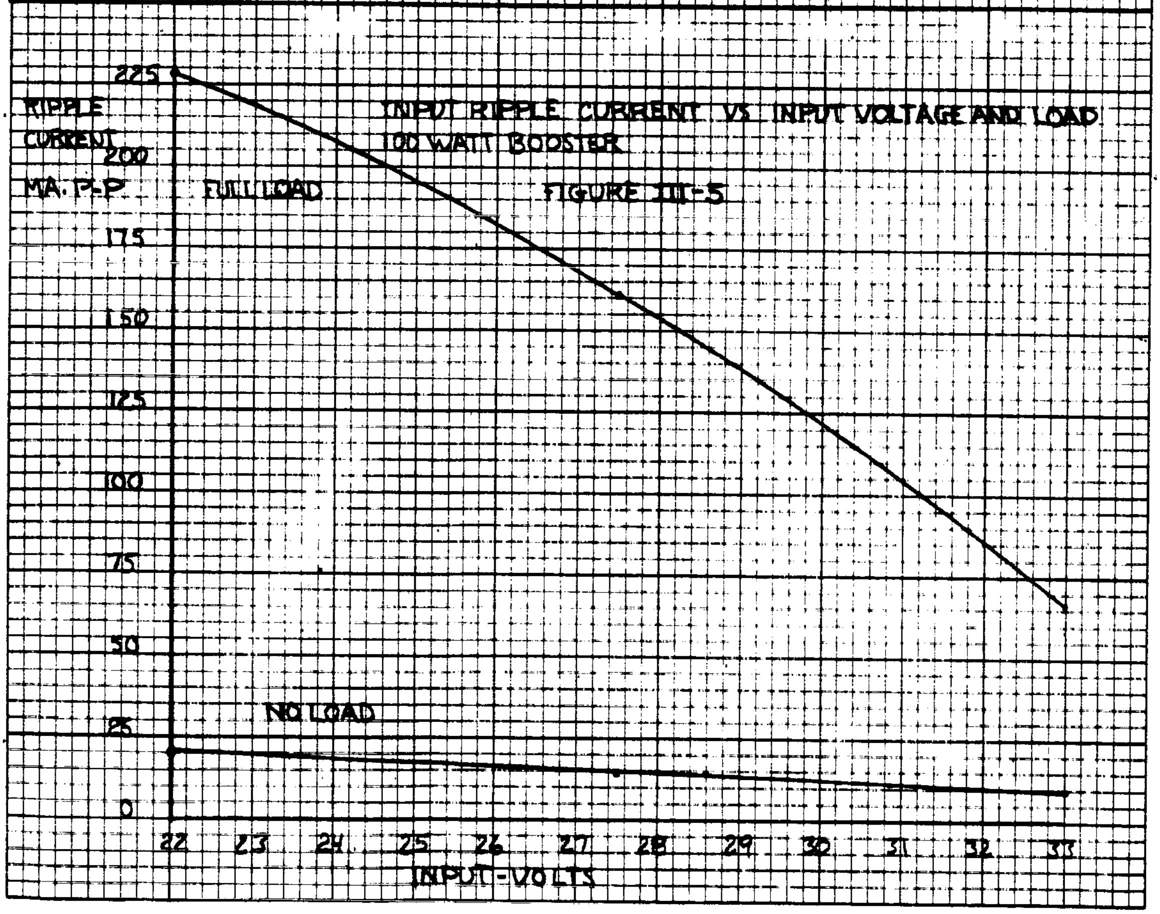
Power Level	Load %	Input Volts	Dynamic Response: Dynamic Regulation Peak Volts	Dynamic Response: Recovery Time Milliseconds
	0	22→33	1.90	10
	0	33→22	.65	30
	100	22→33	1.60	10
100	100	33→22	4.00	10
Watt	100→75	22	.80	10
	75→100	22	.60	10
	100→75	33	.60	10
	75→100	33	.30	10
	0	12→20	.18	0
	0	20→12	.34	40
	100	12→20	.75	10
50	100	20→12	.90	10
Watt	100→75	12	1.05	10
	75→100	12	.80	10
	100→75	20	.70	10
	75→100	20	.50	10
	0	10→20	.75	50
	0	20→10	1.40	50
	100	10→20	1.40	50
25	100	20→10	3.10	50
Watt	100→75	10	.80	20
	75→100	10	.70	20
	100→75	20	.45	10
	75→100	20	.32	10
	0	10→20	.45	10
	0	20→10	.65	50
	100	10→20	.80	20
10	100	20→10	.75	50
Watt	100→75	10	.45	10
	75→100	10	.44	10
	100→75	20	.26	10
	75→100	20	.20	0

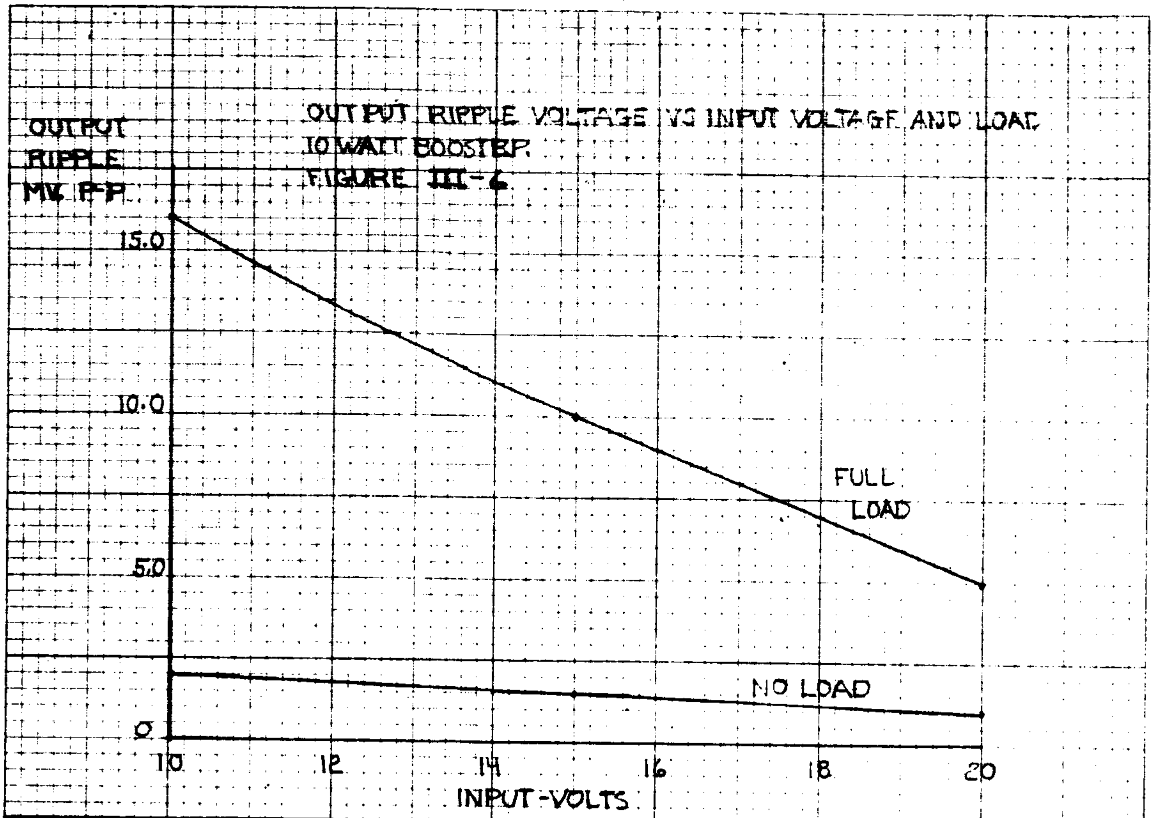

NO LOAD LOSSES -WATTS
FIGURE III-1
NO LOAD LOSSES VS INPUT VOLTAGE
10, 25, 50 AND 100 WATT BOOSTERS
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
100 WATT BOOSTER
50 WATT BOOSTER
10 AND 25 WATT BOOSTER
50 WATT BOOSTER
10 AND 25 WATT BOOSTERS
PROTECTION CIRCUIT ACTIVATED
PROTECTION CIRCUIT DE-ACTIVATED
10
12
14
16
18
20
INPUT VOLTAGE FOR 10, 25 AND 50 WATT BOOSTER
22
23
24
25
26
27
28
29
30
31
32
33
INPUT VOLTAGE FOR 100 WATT BOOSTER

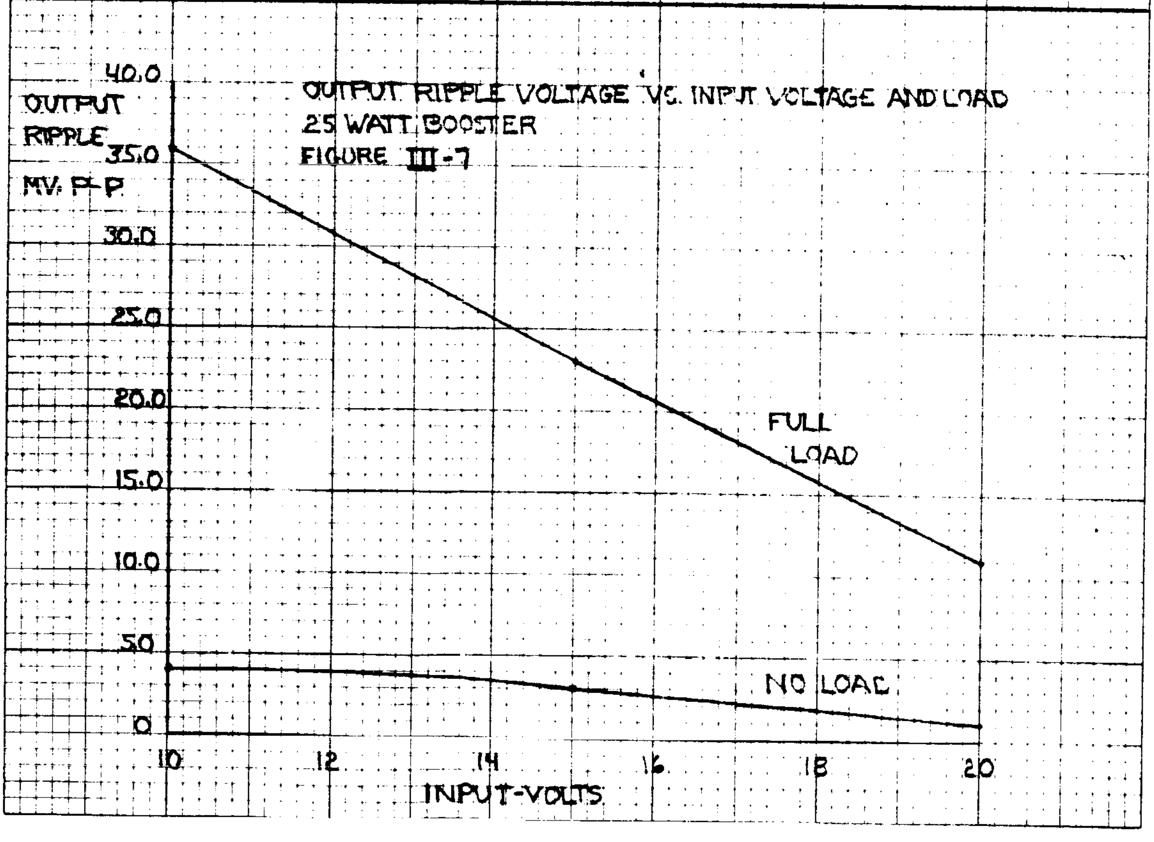

INPUT RIPPLE CURRENT VS INPUT VOLTAGE AND LOAD
10 WATT BOOSTER
FIGURE III-2
RIPPLE CURRENT MA.P-P
14
12
10
8
6
4
2
0
10
12
14
16
18
20
INPUT-VOLTS
FULL LOAD
NO LOAD

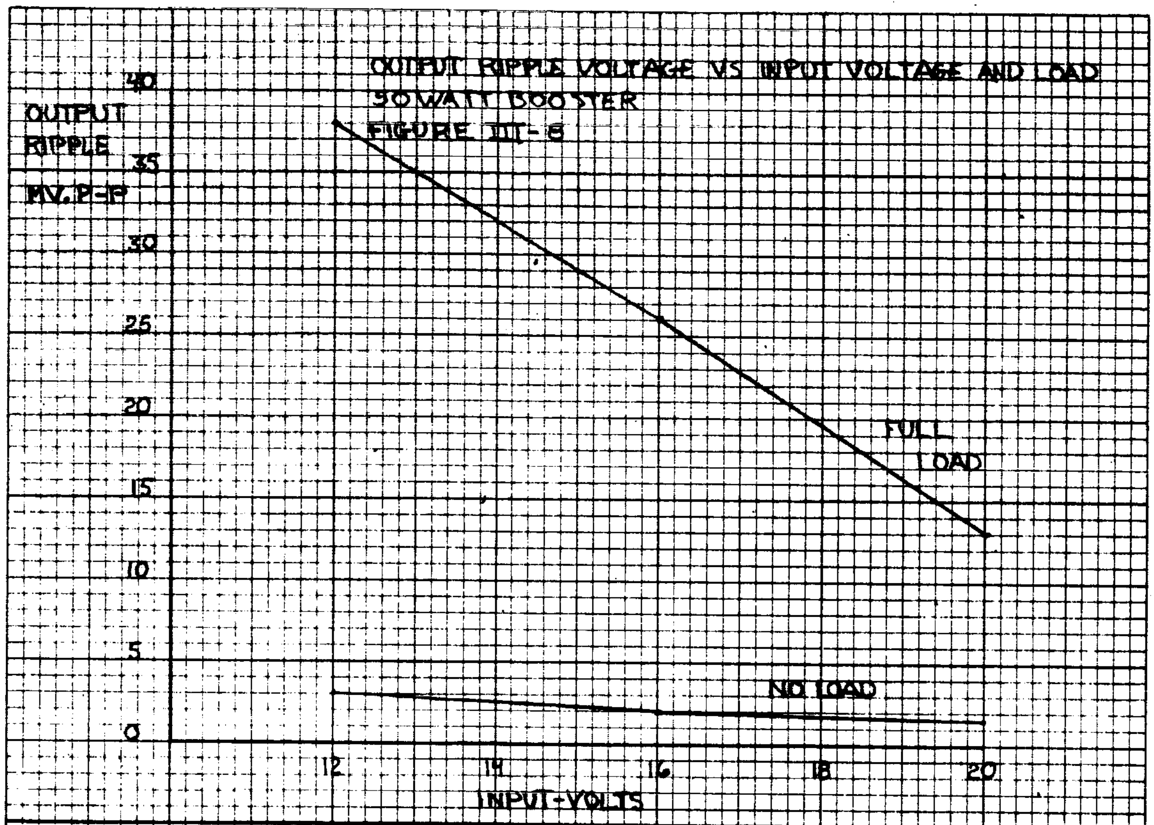

INPUT RIPPLE CURRENT VS. INPUT VOLTAGE AND LOAD
25 WATT BOOSTER
FIGURE III-3
RIPPLE CURRENT MA.P-P
40
35
30
25
20
15
10
5
0
10
12
14
16
18
20
INPUT-VOLTS
FULL LOAD
NO LOAD

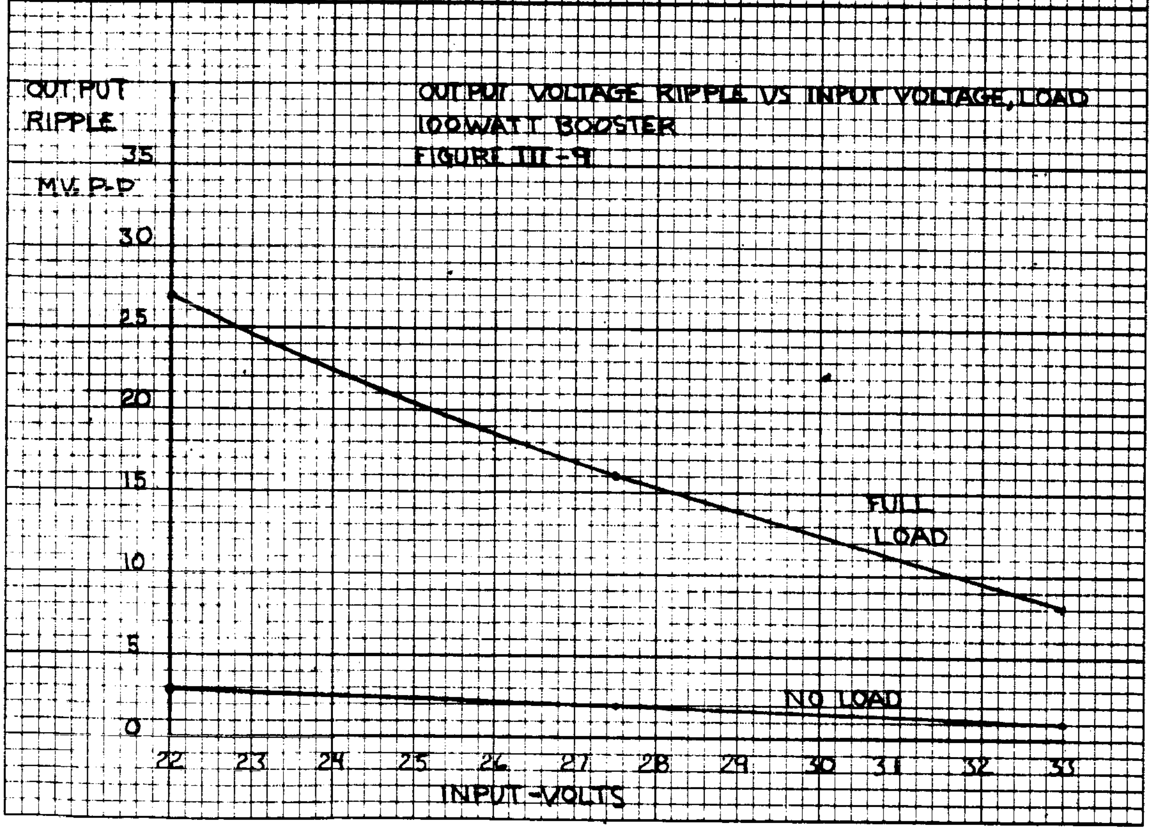

INPUT RIPPLE CURRENT VS INPUT VOLTAGE AND LOAD
50 WATT BOOSTER
FIGURE III-4
RIPPLE CURRENT MA. P-P
FULL LOAD
NO LOAD
40
30
20
10
0
12
14
16
18
20
INPUT-VOLTS

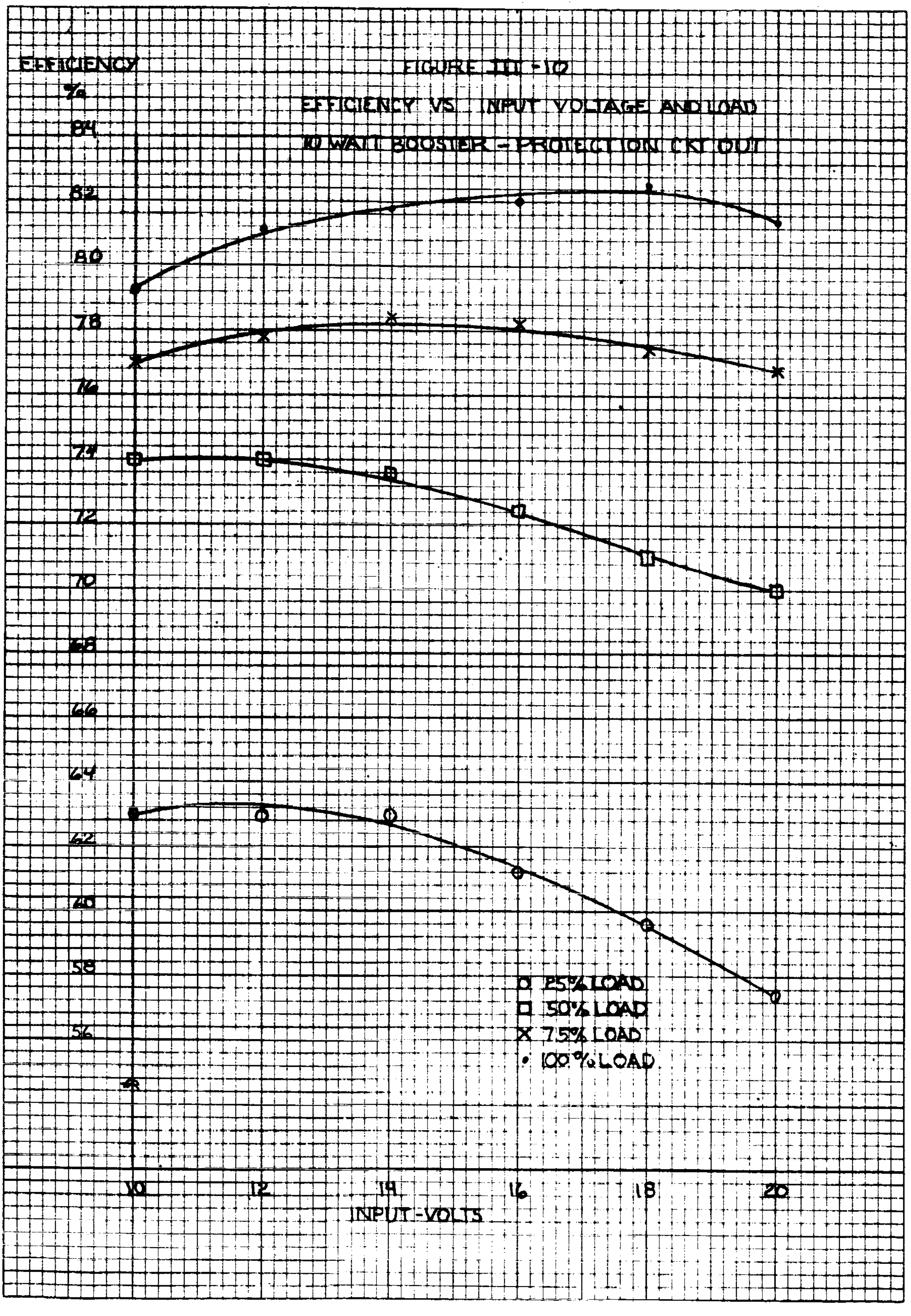

INPUT RIPPLE CURRENT VS INPUT VOLTAGE AND LOAD
100 WATT BOOSTER
FIGURE III-5
RIPPLE CURRENT MA. P-P
FULL LOAD
NO LOAD
225
200
175
150
125
100
75
50
25
0
22
23
24
25
26
27
28
29
30
31
32
33
INPUT-VOLTS


OUTPUT RIPPLE VOLTAGE VS INPUT VOLTAGE AND LOAD
10 WATT BOOSTER
FIGURE III-6
OUTPUT RIPPLE MV P-P
15.0
10.0
5.0
0
10
12
14
16
18
20
INPUT-VOLTS
FULL LOAD
NO LOAD


OUTPUT RIPPLE VOLTAGE VS. INPUT VOLTAGE AND LOAD
25 WATT BOOSTER
FIGURE III-7
OUTPUT RIPPLE MV. P-P
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0
10
12
14
16
18
20
INPUT-VOLTS
FULL LOAD
NO LOAD


OUTPUT RIPPLE VOLTAGE VS INPUT VOLTAGE AND LOAD
50 WATT BOOSTER
FIGURE III-8
OUTPUT
RIPPLE
MV. P-P
40
35
30
25
20
15
10
5
0
FULL
LOAD
NO LOAD
12
14
16
18
20
INPUT-VOLTS


OUTPUT VOLTAGE RIPPLE VS INPUT VOLTAGE, LOAD
100 WATT BOOSTER
FIGURE III-9
OUTPUT
RIPPLE
MV. P-P
35
30
25
20
15
10
5
0
FULL
LOAD
NO LOAD
22
23
24
25
26
27
28
29
30
31
32
33
INPUT-VOLTS



NO. 340R-10 DIETZGEN GRAPH PAPER 10 X 10 PER INCH
EUGENE DIETZGEN CO. MADE IN U. S. A.

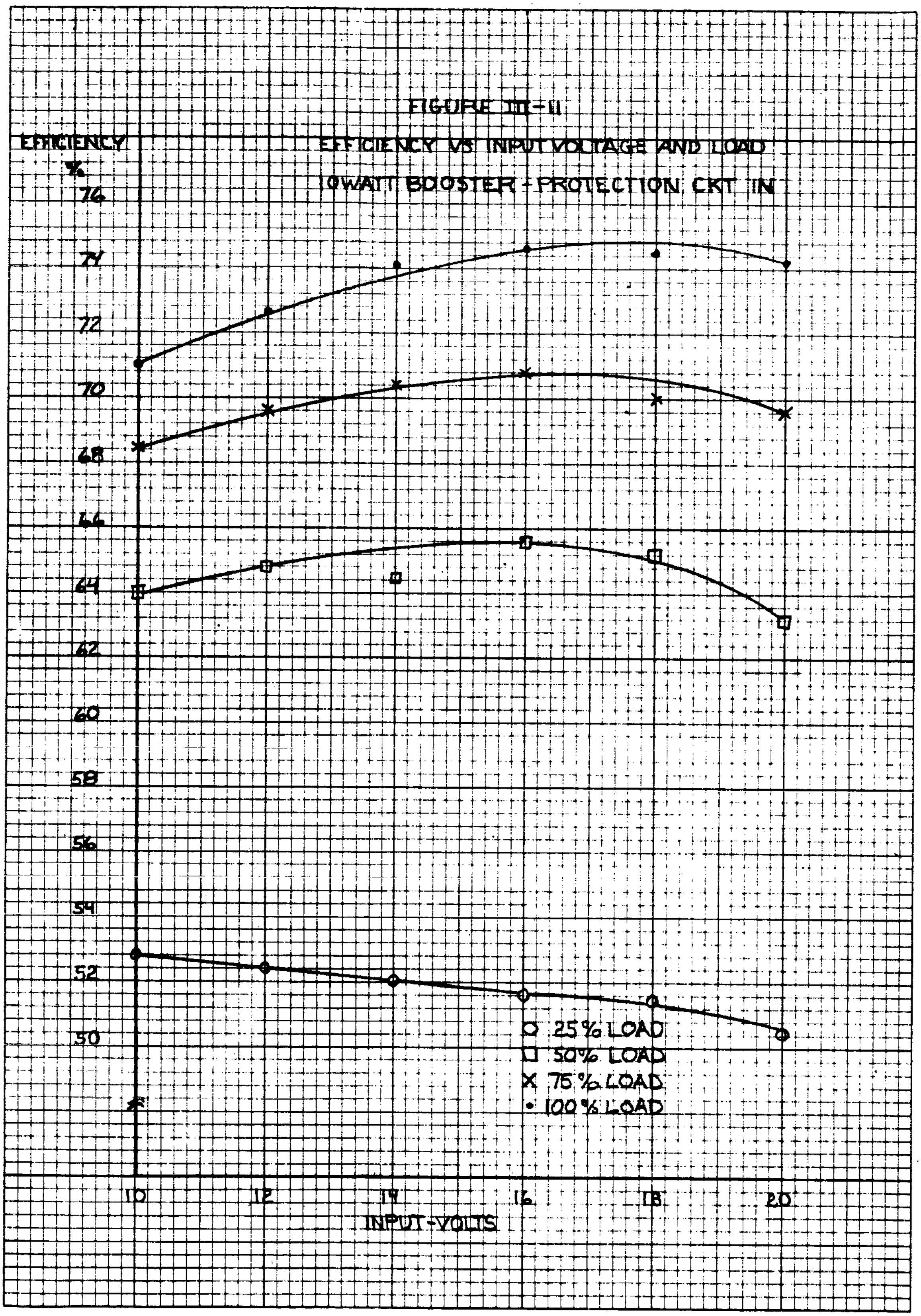


FIGURE III-11
EFFICIENCY VS INPUT VOLTAGE AND LOAD
10 WATT BOOSTER - PROTECTION CKT IN
EFFICIENCY %
76
74
72
70
68
66
64
62
60
58
56
54
52
50
○ 25% LOAD
□ 50% LOAD
X 75% LOAD
• 100% LOAD
10
12
14
16
18
20
INPUT-VOLTS

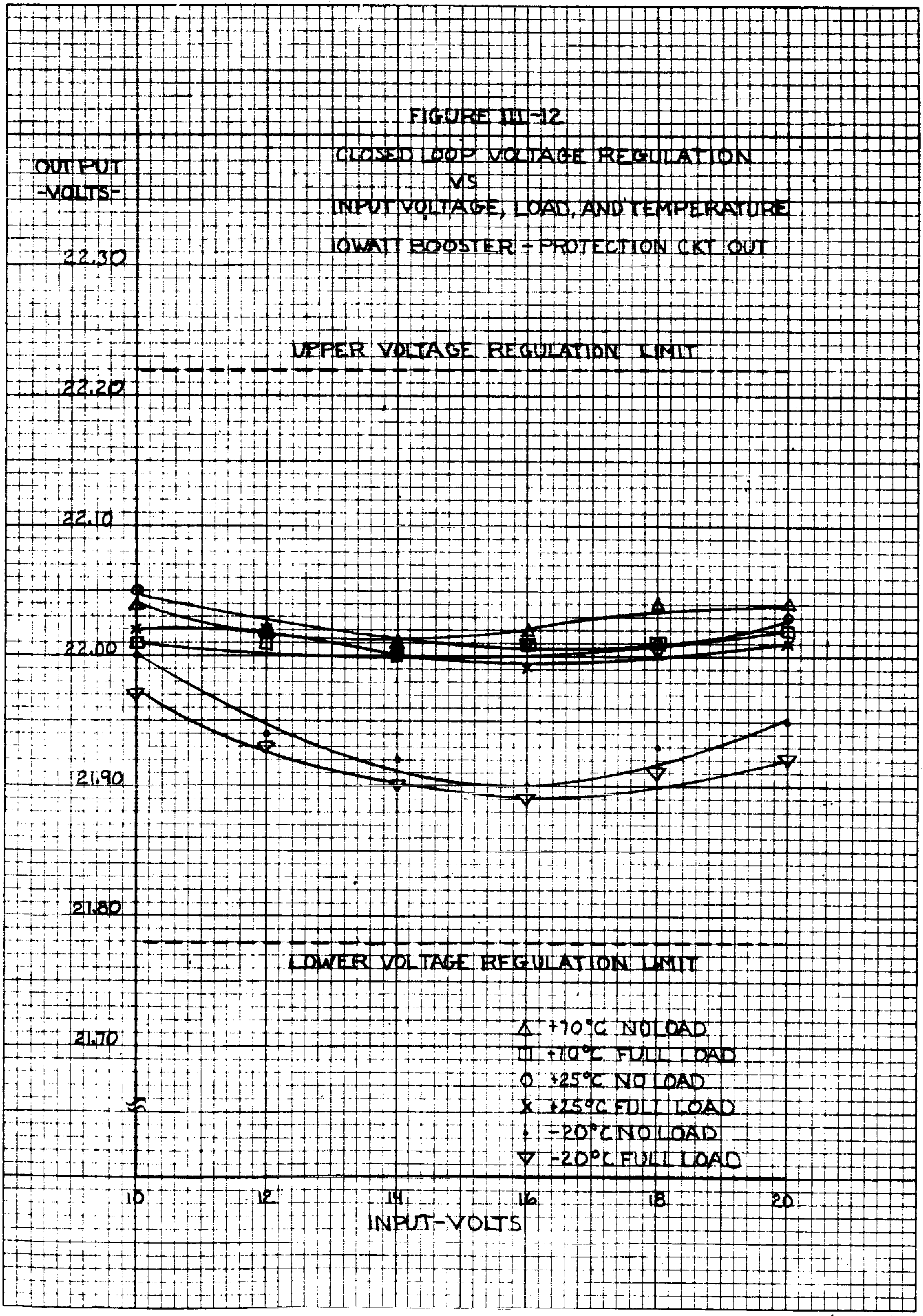
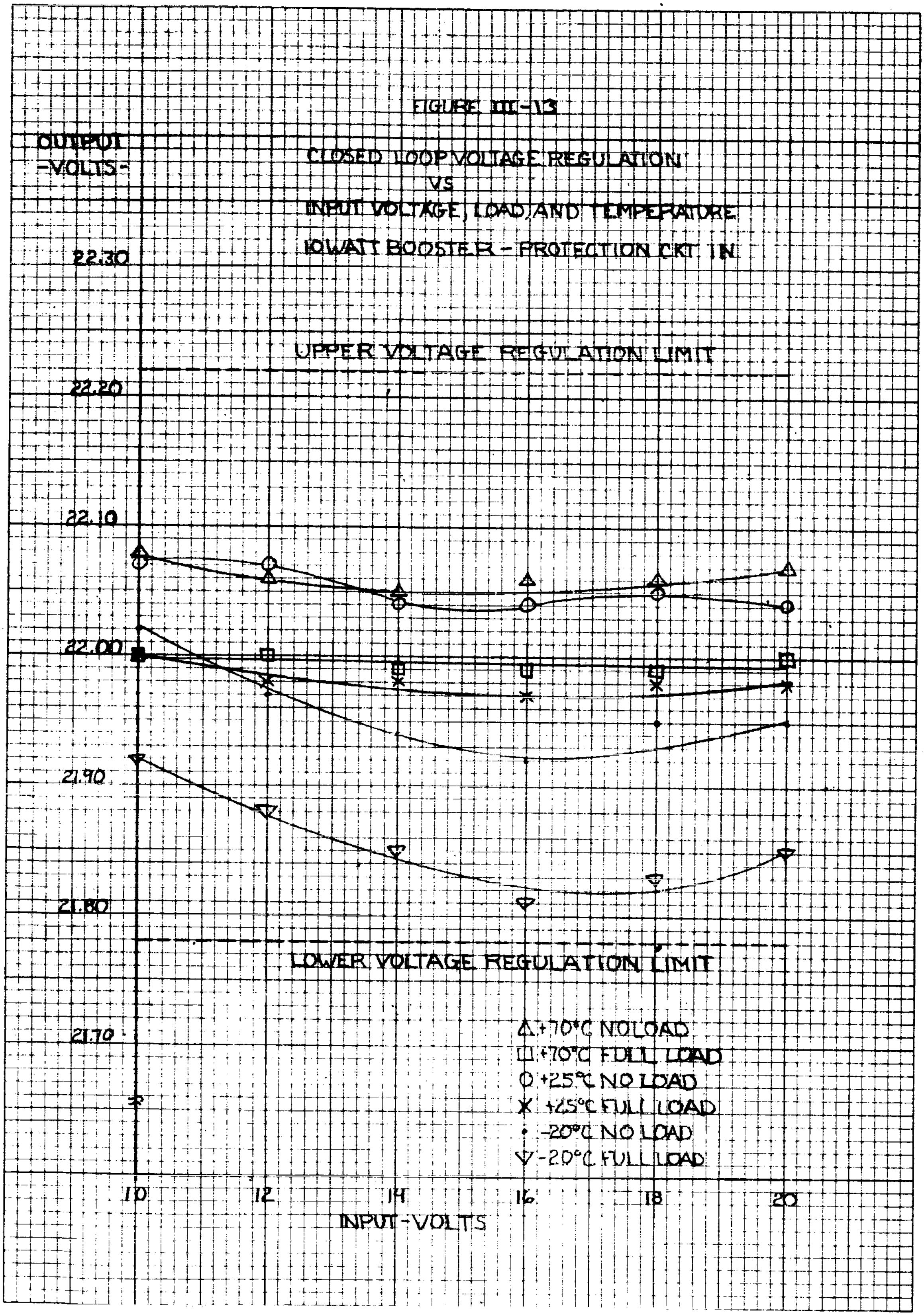


FIGURE III-12
CLOSED LOOP VOLTAGE REGULATION
VS
INPUT VOLTAGE, LOAD, AND TEMPERATURE
10WATT BOOSTER - PROTECTION CKT OUT
OUTPUT
-VOLTS-
22.30
22.20
22.10
22.00
21.90
21.80
21.70
UPPER VOLTAGE REGULATION LIMIT
LOWER VOLTAGE REGULATION LIMIT
+70°C NO LOAD
+70°C FULL LOAD
+25°C NO LOAD
+25°C FULL LOAD
-20°C NO LOAD
-20°C FULL LOAD
10
12
14
16
18
20
INPUT-VOLTS



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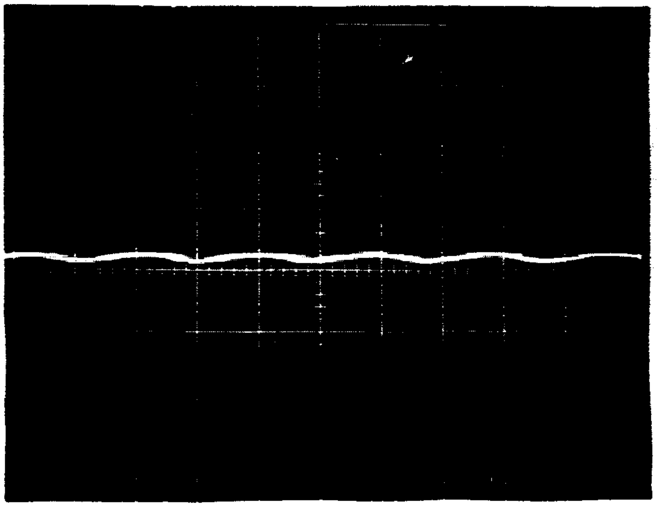
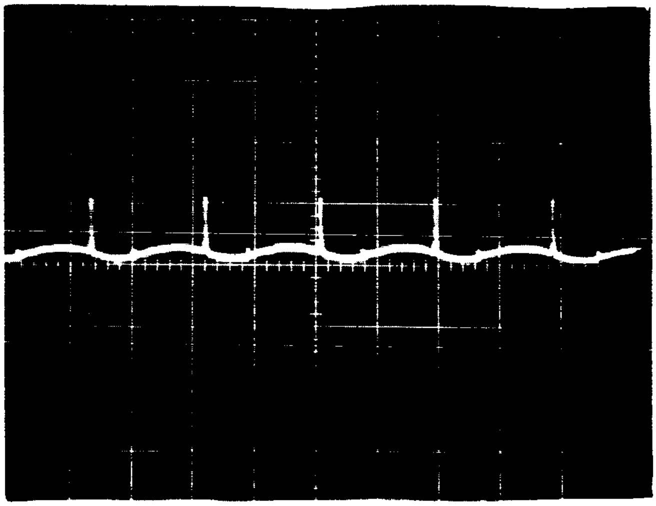
NO. 340R-10 DIETZGEN GRAPH PAPER 10 X 10 PER INCH

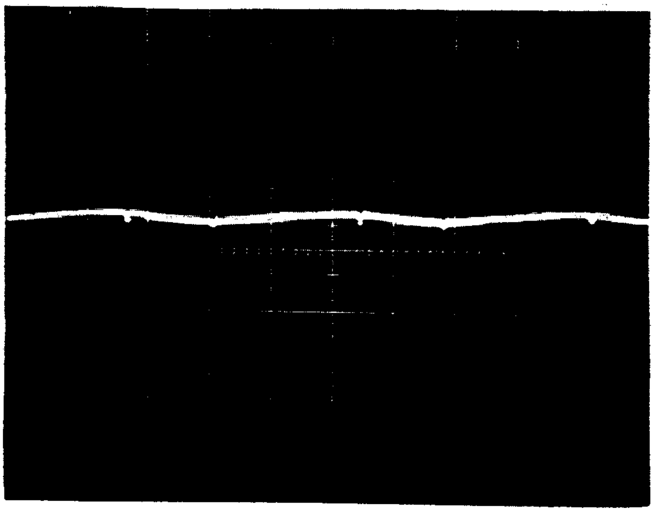


Input Ripple Current No Load 15 Volt Input
Vertical Scale 35.7 ma/Div.
Horizontal Scale 20 μsec/Div.

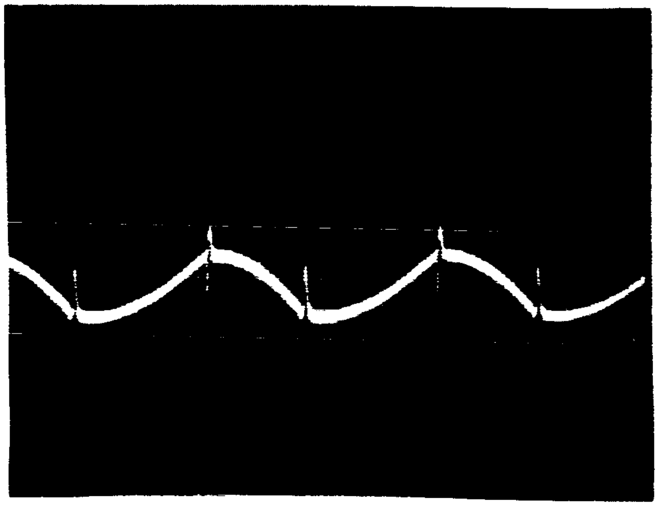


Input Ripple Current Full Load 15 Volt Input
Vertical Scale 35.7 ma/Div.
Horizontal Scale 20 μsec/Div.

Figure III-14 Input Ripple Current 10 Watt Booster

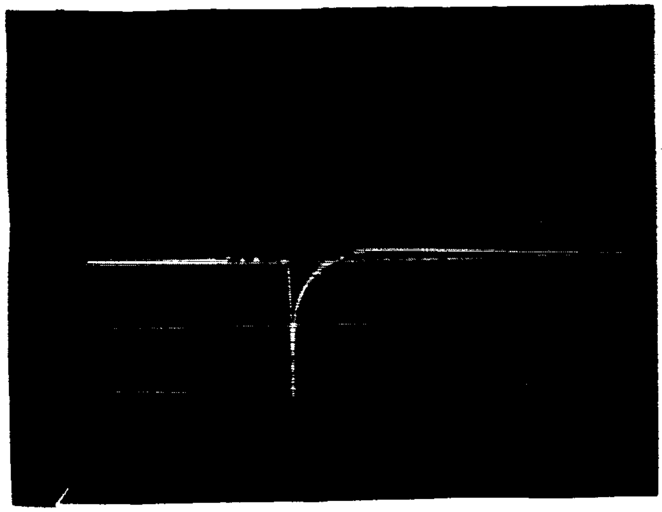


Output Ripple Voltage No Load 15 Volt Input
Vertical Scale 10 MV/Div.
Horizontal Scale 10 μsec/Div.

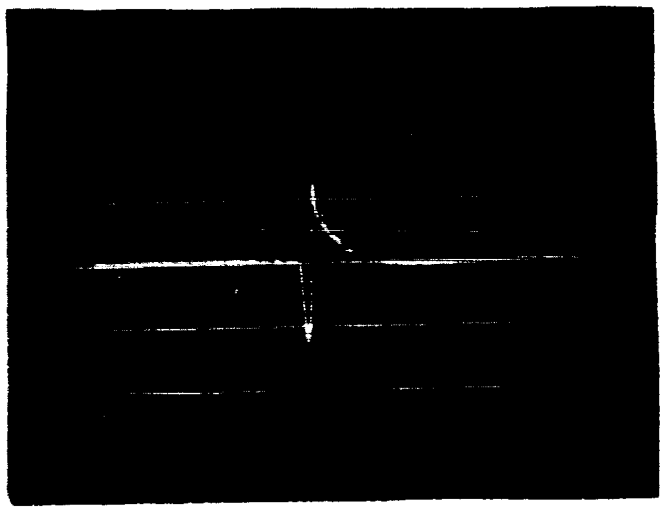


Output Ripple Voltage Full Load 15 Volt Input
Vertical Scale 10 MV/Div.
Horizontal Scale 10 μsec/Div.

Figure III-15 Output Ripple Voltage 10 Watt Booster

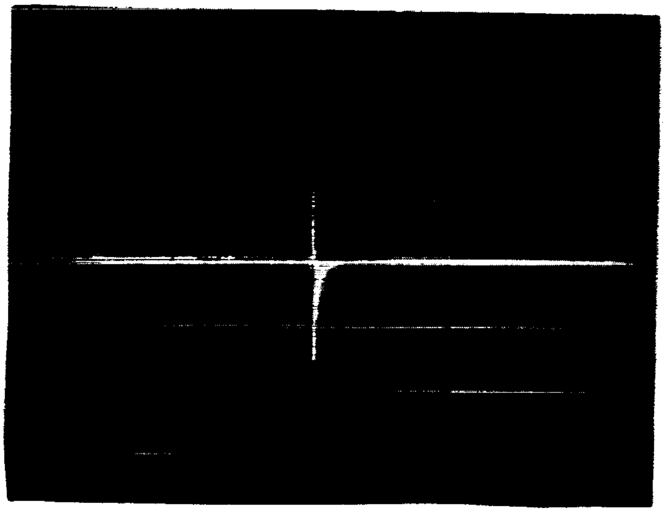


10 To 20 Volts Input At No Load Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale .1 Sec/Div.

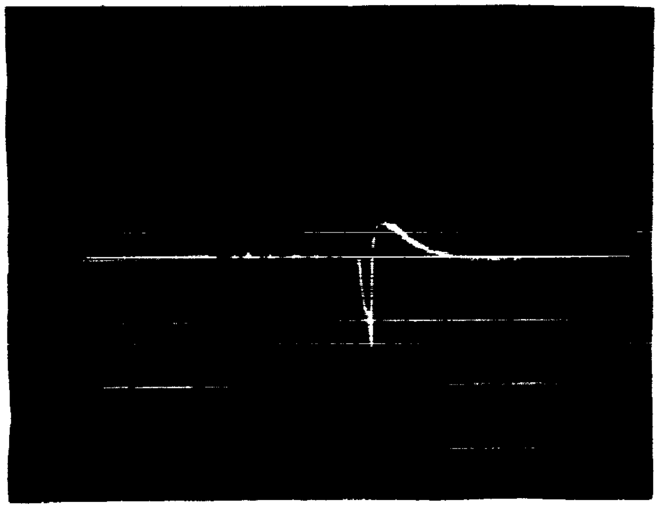


20 To 10 Volts Input At No Load Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-16 Dynamic Response 10 Watt Booster

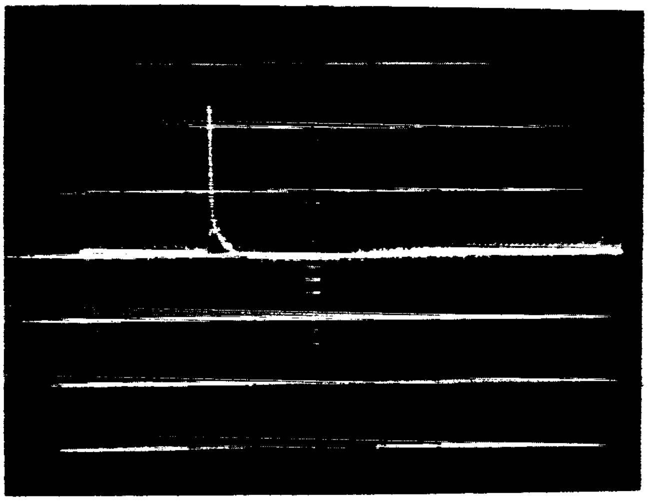


10 To 20 Volts Input At Full Load Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

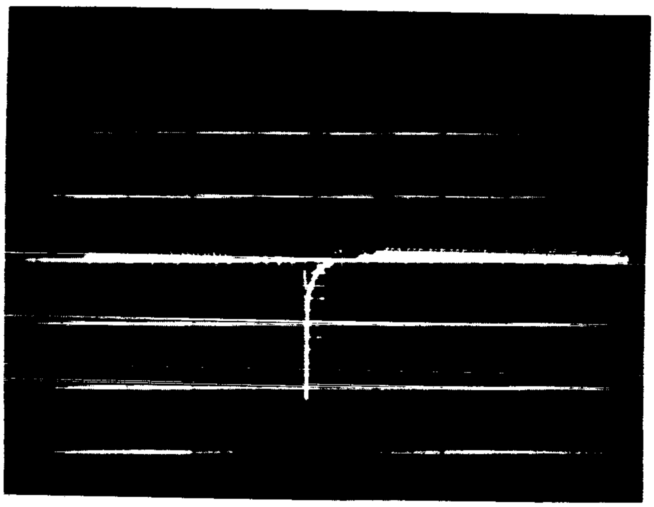


20 To 10 Volts Input At Full Load Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-17   Dynamic Response 10 Watt Booster

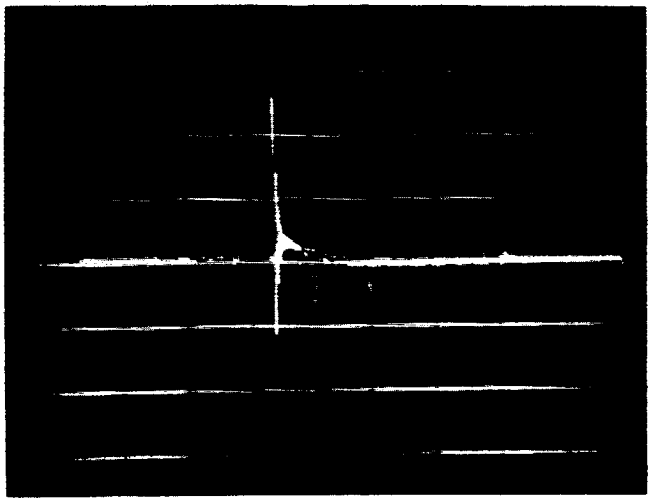


Full Load To 3/4 At 10 Volts In Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale .1 Sec/Div.

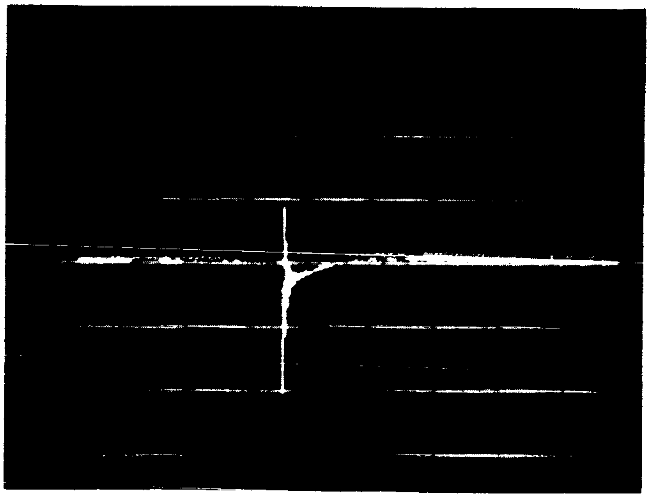


3/4 To Full Load At 10 Volts In Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-18 Dynamic Response 10 Watt Booster



Full Load To 3/4 At 20 Volts In Output
Voltage Transient
Vertical Scale .1 V/Div.
Horizontal Scale .1 Sec/Div.



3/4 To Full Load At 20 Volts In Output
Voltage Transient
Vertical Scale .1 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-19 Dynamic Response 10 Watt Booster

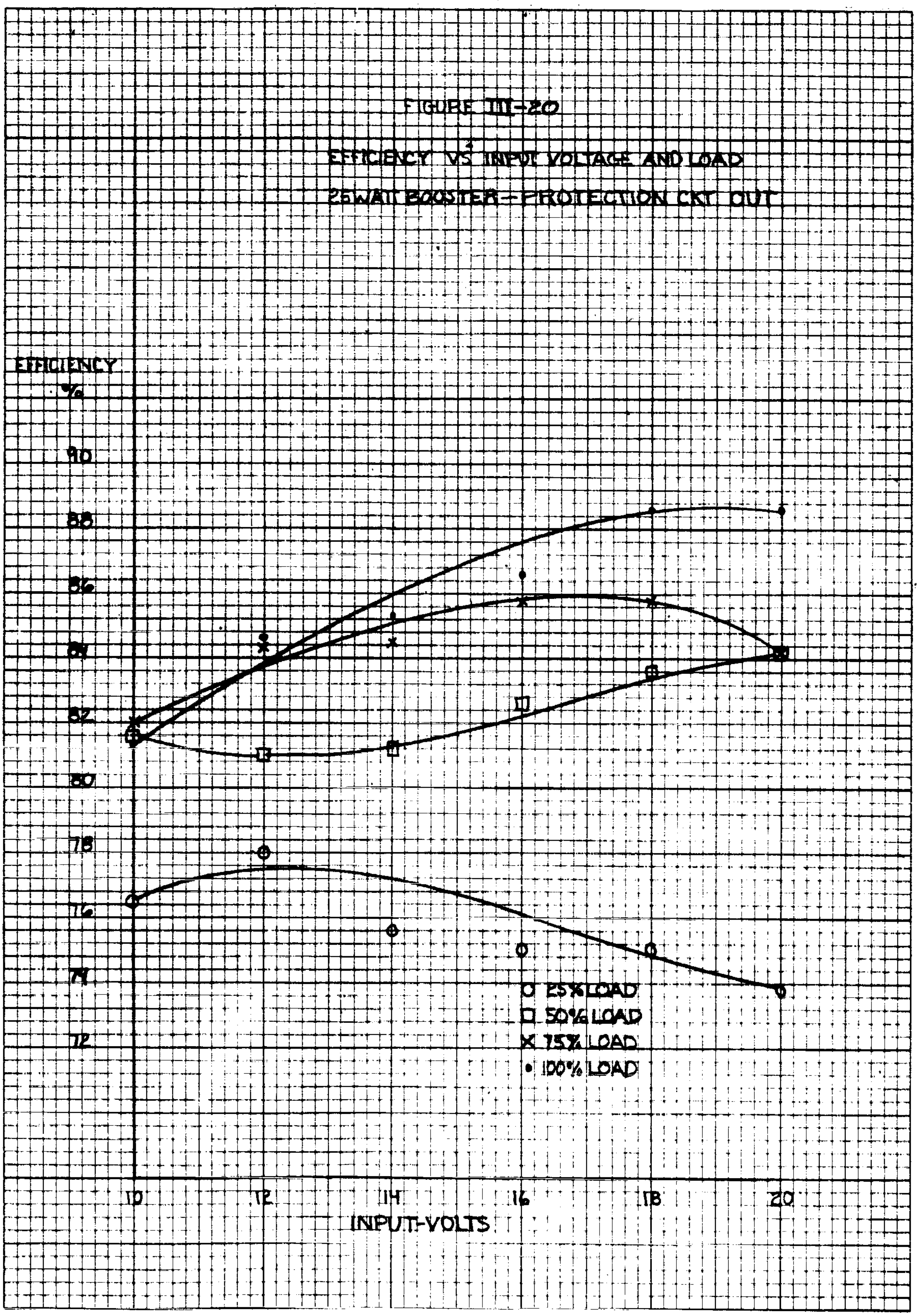


FIGURE III-20
EFFICIENCY VS INPUT VOLTAGE AND LOAD
25WATT BOOSTER - PROTECTION CKT OUT
EFFICIENCY
%
90
88
86
84
82
80
78
76
74
72
o 25% LOAD
□ 50% LOAD
X 75% LOAD
• 100% LOAD
10
12
14
16
18
20
INPUT-VOLTS

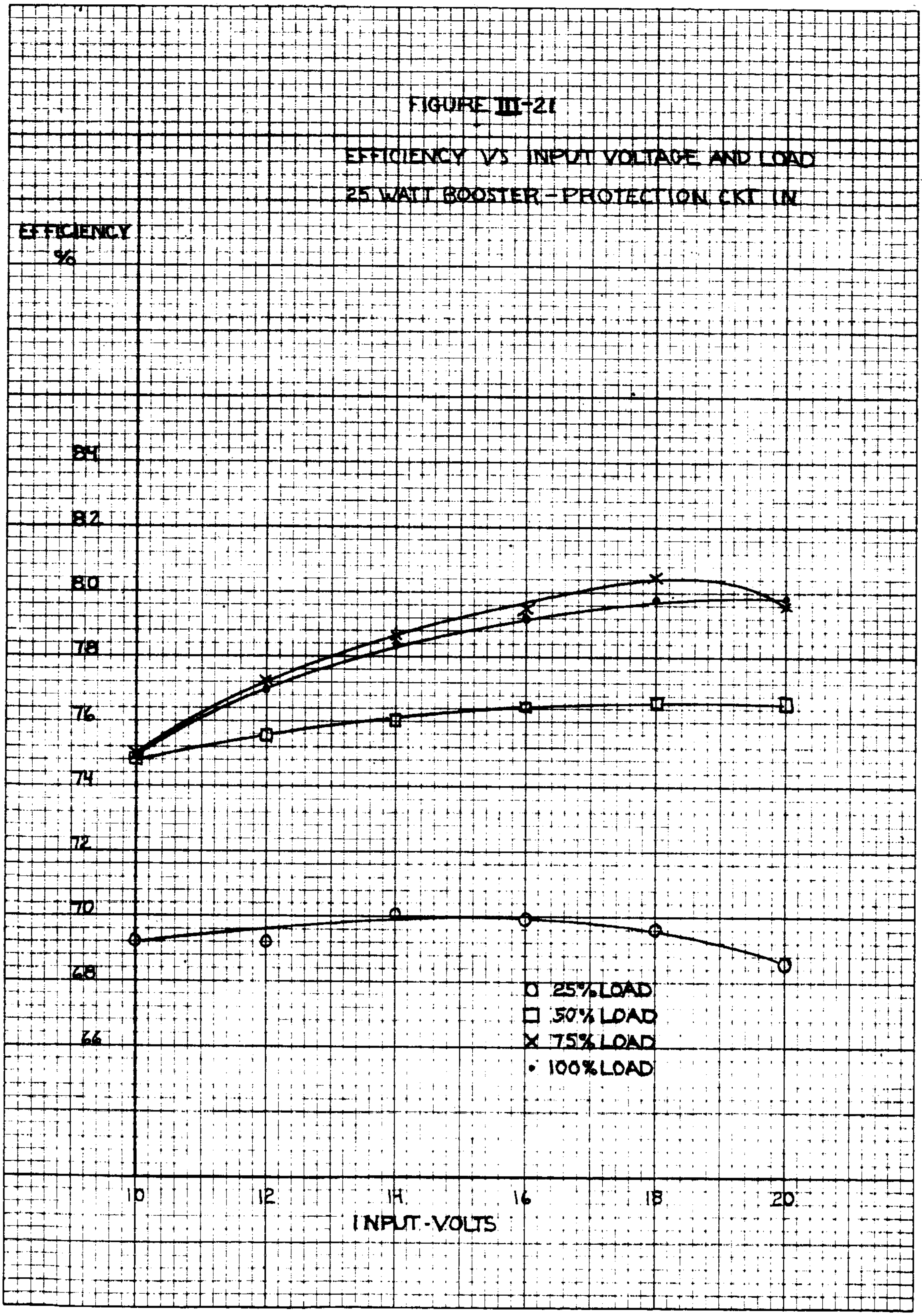


FIGURE III-21
EFFICIENCY VS INPUT VOLTAGE AND LOAD
25 WATT BOOSTER - PROTECTION CKT IN
EFFICIENCY %
84
82
80
78
76
74
72
70
68
66
10
12
14
16
18
20
INPUT-VOLTS
25% LOAD
50% LOAD
75% LOAD
100% LOAD

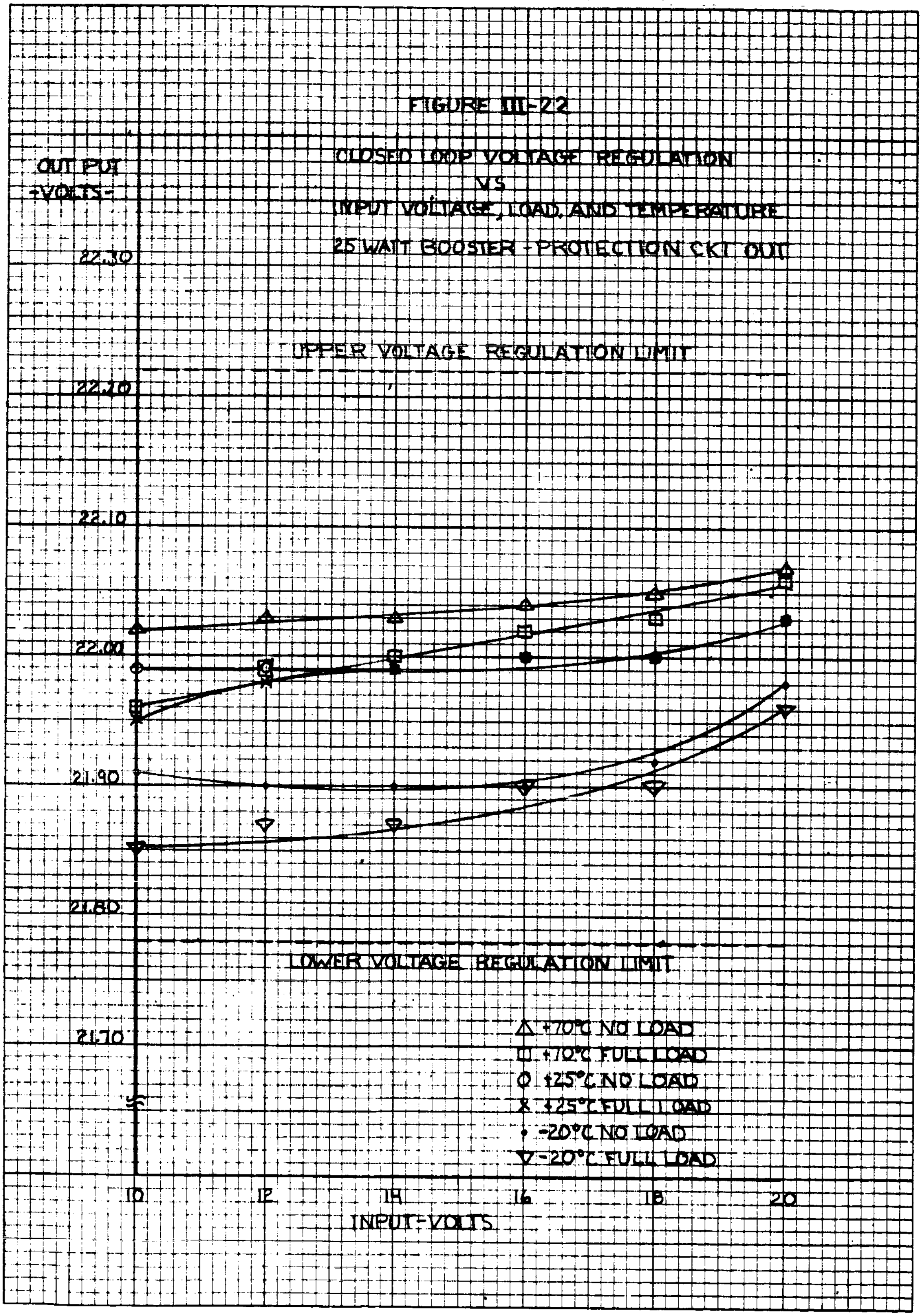


FIGURE III-22
CLOSED LOOP VOLTAGE REGULATION
VS
INPUT VOLTAGE, LOAD, AND TEMPERATURE
25 WATT BOOSTER - PROTECTION CKT OUT
OUT PUT
-VOLTS-
22.30
22.20
22.10
22.00
21.90
21.80
21.70
UPPER VOLTAGE REGULATION LIMIT
LOWER VOLTAGE REGULATION LIMIT
+70°C NO LOAD
+70°C FULL LOAD
+25°C NO LOAD
+25°C FULL LOAD
-20°C NO LOAD
-20°C FULL LOAD
10
12
14
16
18
20
INPUT-VOLTS

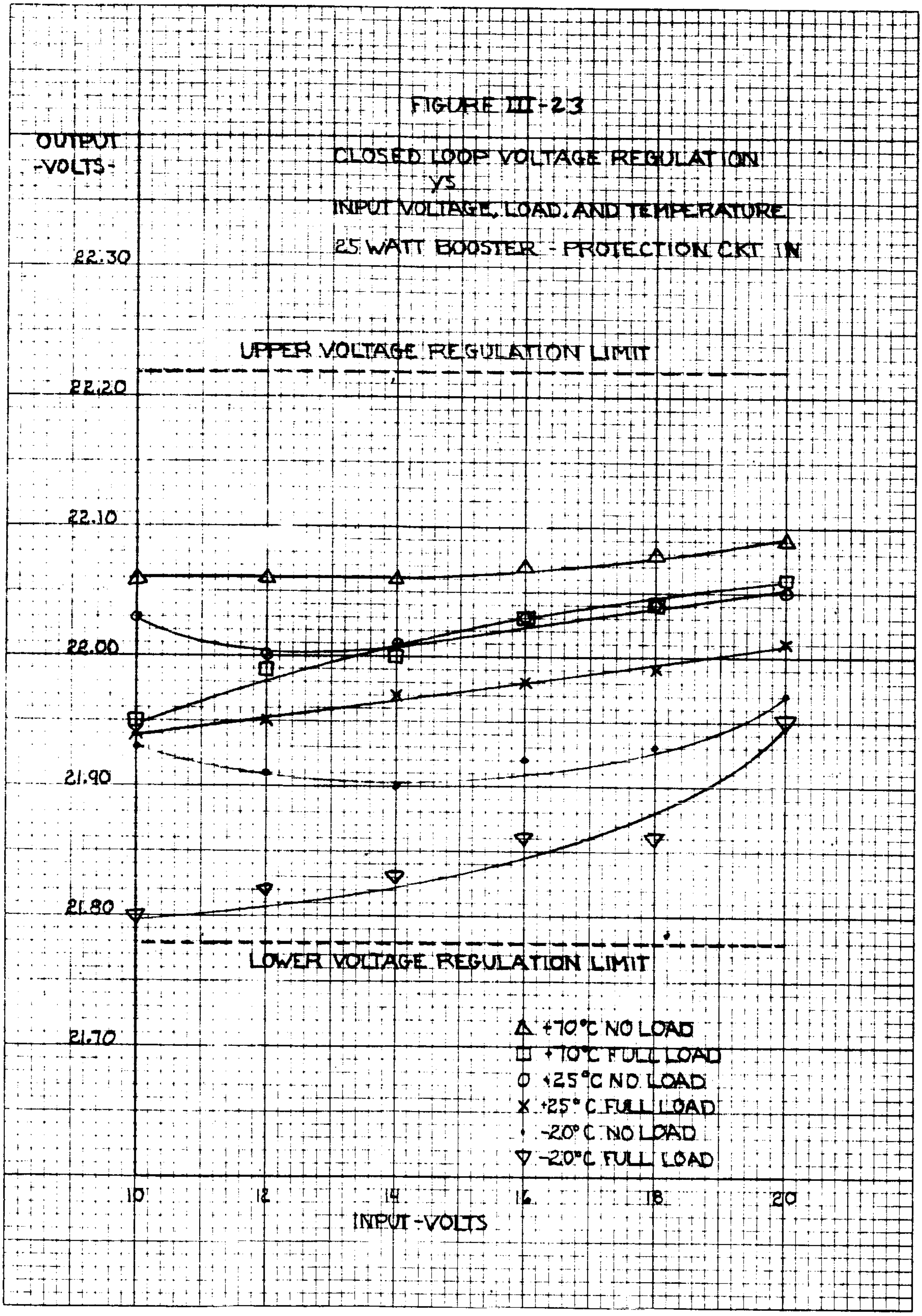
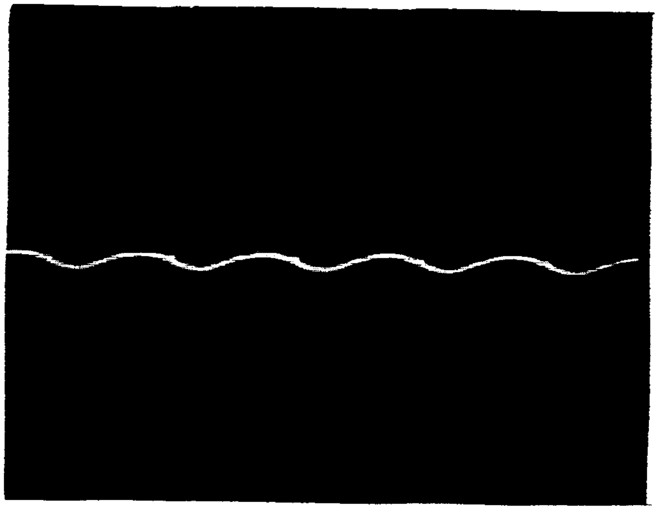
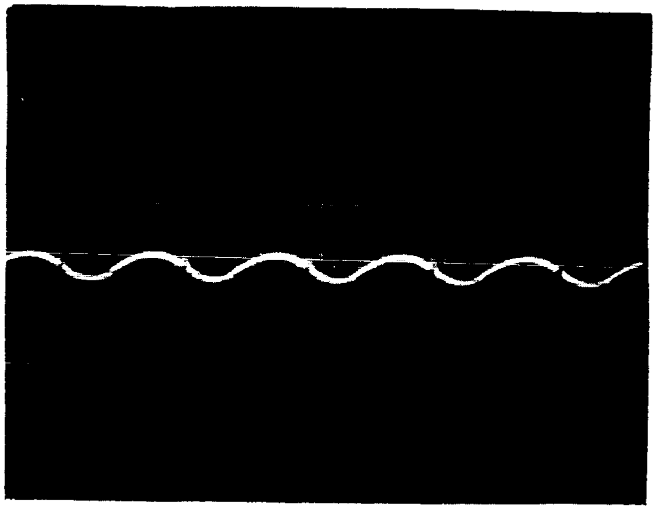


FIGURE III-23
CLOSED LOOP VOLTAGE REGULATION
VS
INPUT VOLTAGE, LOAD, AND TEMPERATURE
25 WATT BOOSTER - PROTECTION CKT IN
OUTPUT
-VOLTS-
22.30
22.20
22.10
22.00
21.90
21.80
21.70
UPPER VOLTAGE REGULATION LIMIT
LOWER VOLTAGE REGULATION LIMIT
+70°C NO LOAD
+70°C FULL LOAD
+25°C NO LOAD
+25°C FULL LOAD
-20°C NO LOAD
-20°C FULL LOAD
10
12
14
16
18
20
INPUT-VOLTS

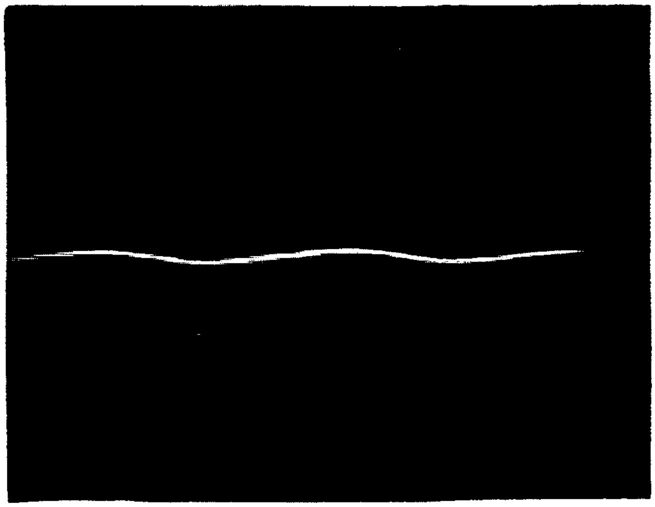


Input Ripple Current No Load 15 Volt Input
Vert. Scale: 35.7 ma/Div
Horz. Scale: 20 μsec/Div.

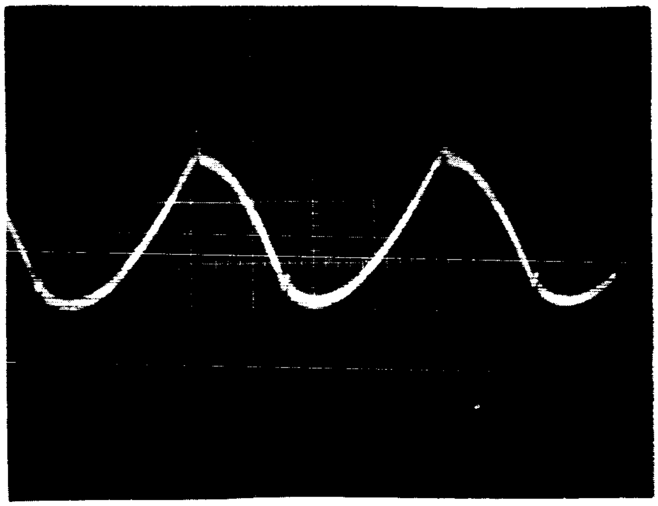


Input Ripple Current Full Load 15 Volt Input
Vert. Scale: 35.7 ma/Div
Horz. Scale: 20 μsec/Div

Figure III-24 Input Ripple Current 25 Watt Booster

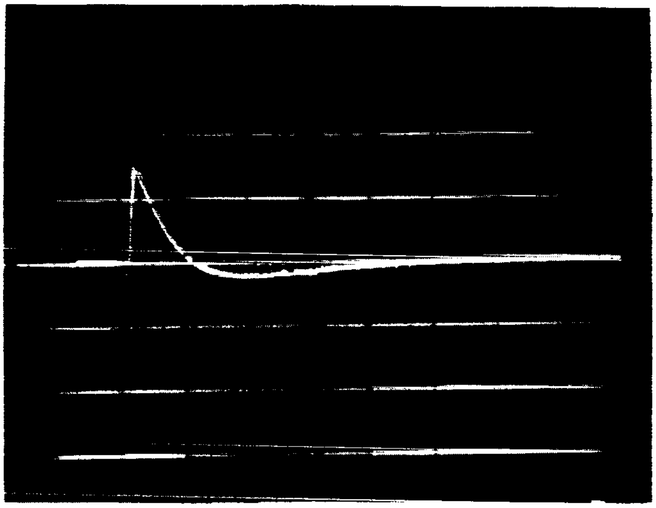


Output Voltage Ripple No Load 15 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

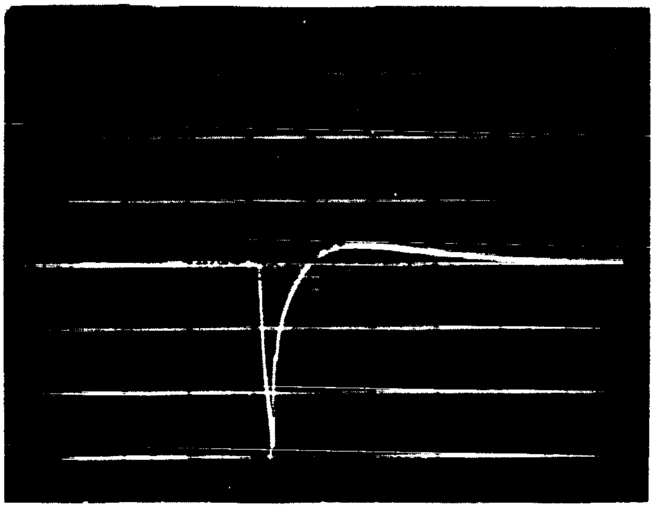


Output Voltage Ripple No Load 15 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

Figure III-25 Output Ripple Voltage 25 Watt Booster

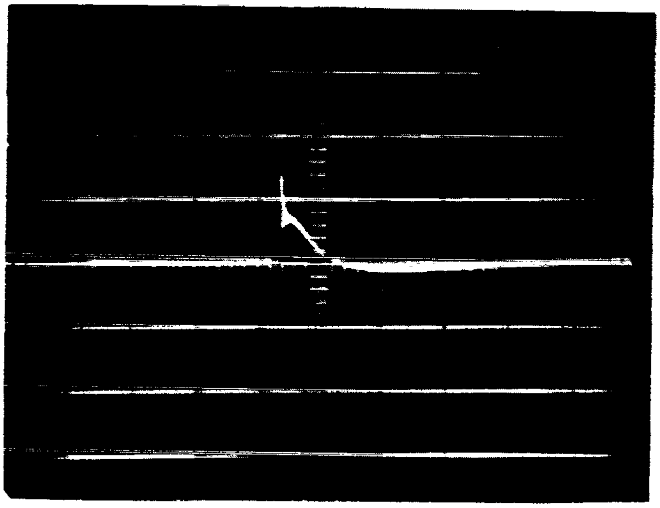


10 To 20 Volts Input At No Load Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

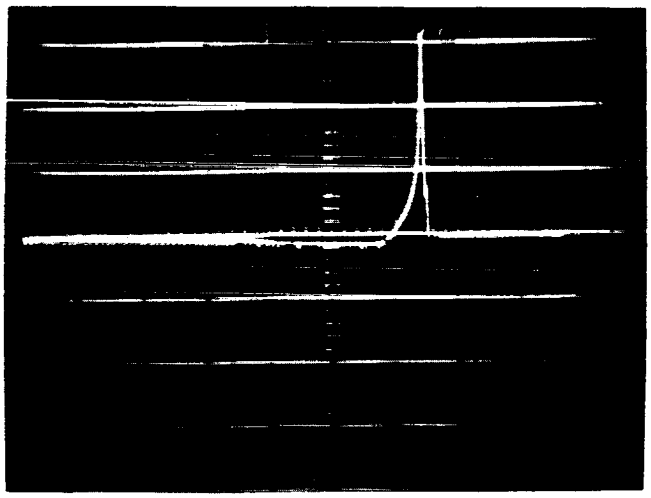


20 To 10 Volts Input At No Load Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-26 Dynamic Response 25 Watt Booster

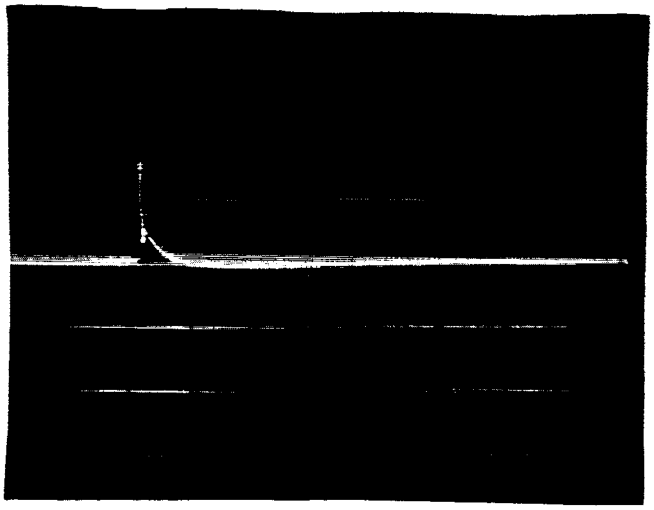


10 to 20 Volts Input At Full Load Output
Voltage Transient
Vertical Scale 1.0 V/Div.
Horizontal Scale .1 Sec/Div.

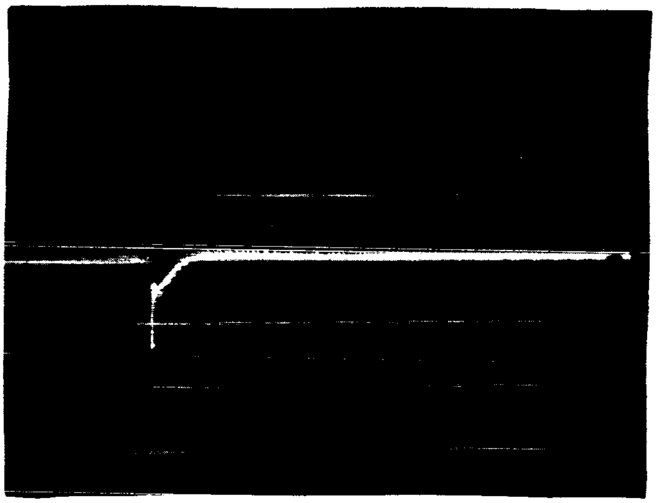


20 To 10 Volts Input At Full Load Output
Voltage Transient
Vertical Scale 1.0 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-27 Dynamic Response 25 Watt Booster

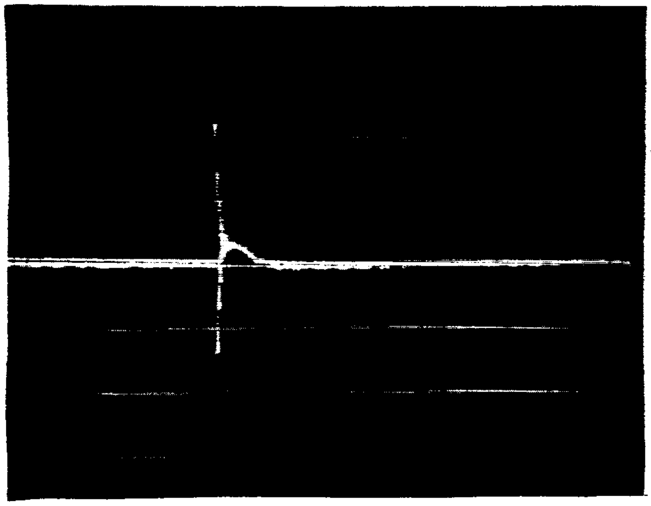


Full Load To 3/4 At 10 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

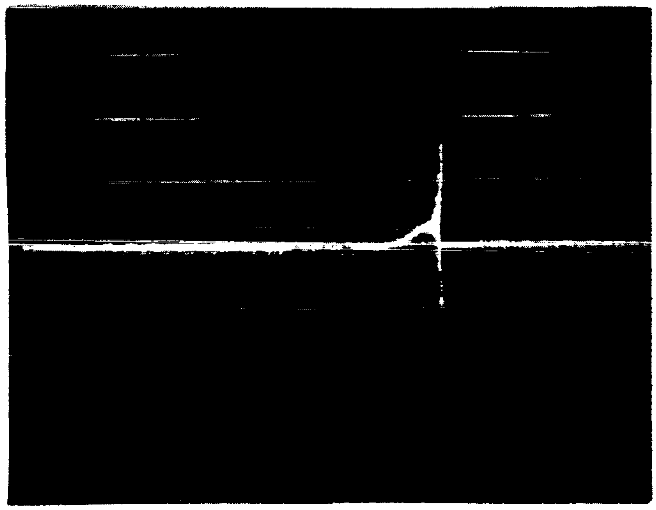


3/4 To Full Load At 10 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-28 Dynamic Response 25 Watt Booster



Full Load To 3/4 At 20 Volts In Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale 1 V/Div.



3/4 To Full Load At 20 Volts In Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III=29 Dynamic Response 25 Watt Booster

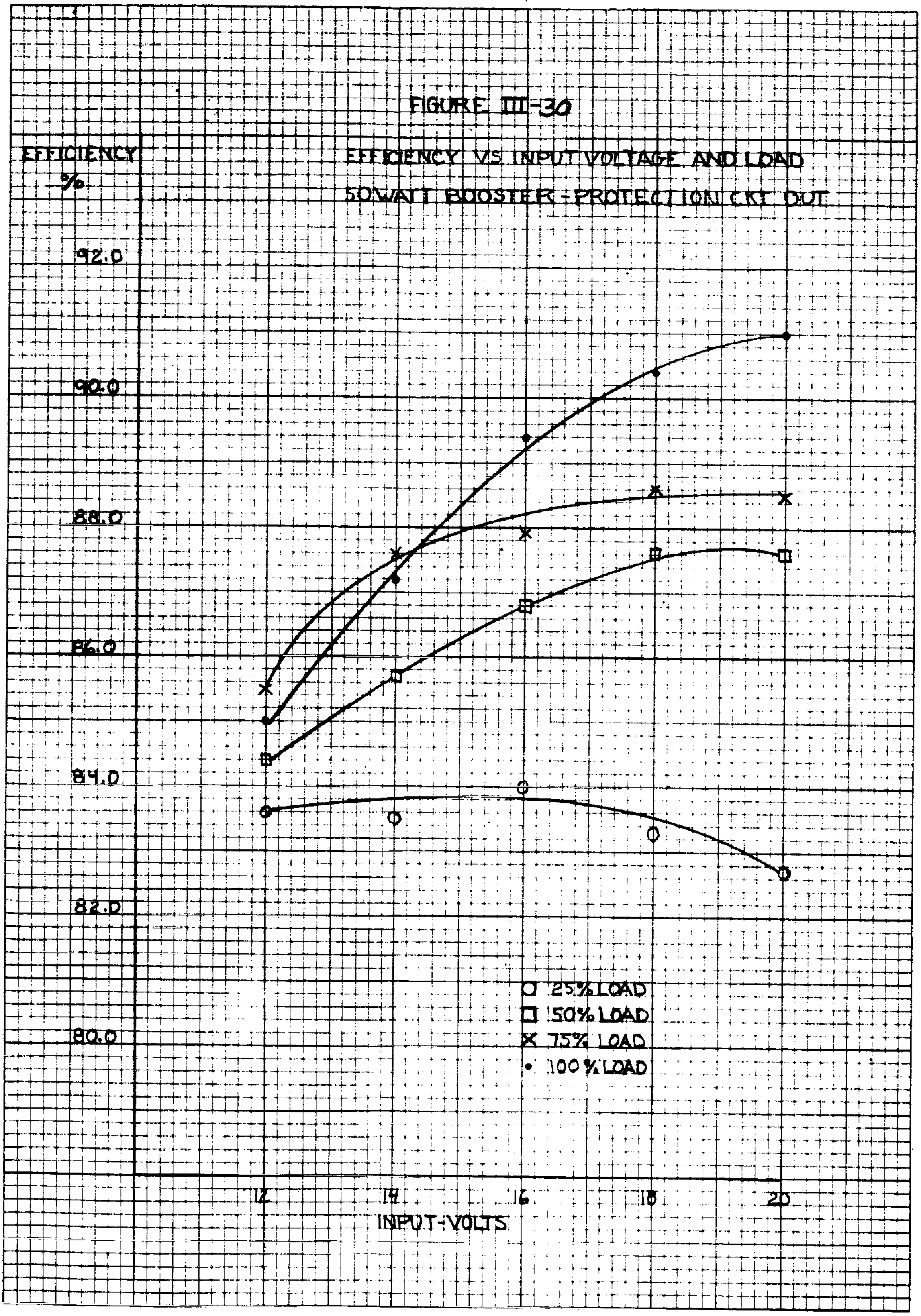
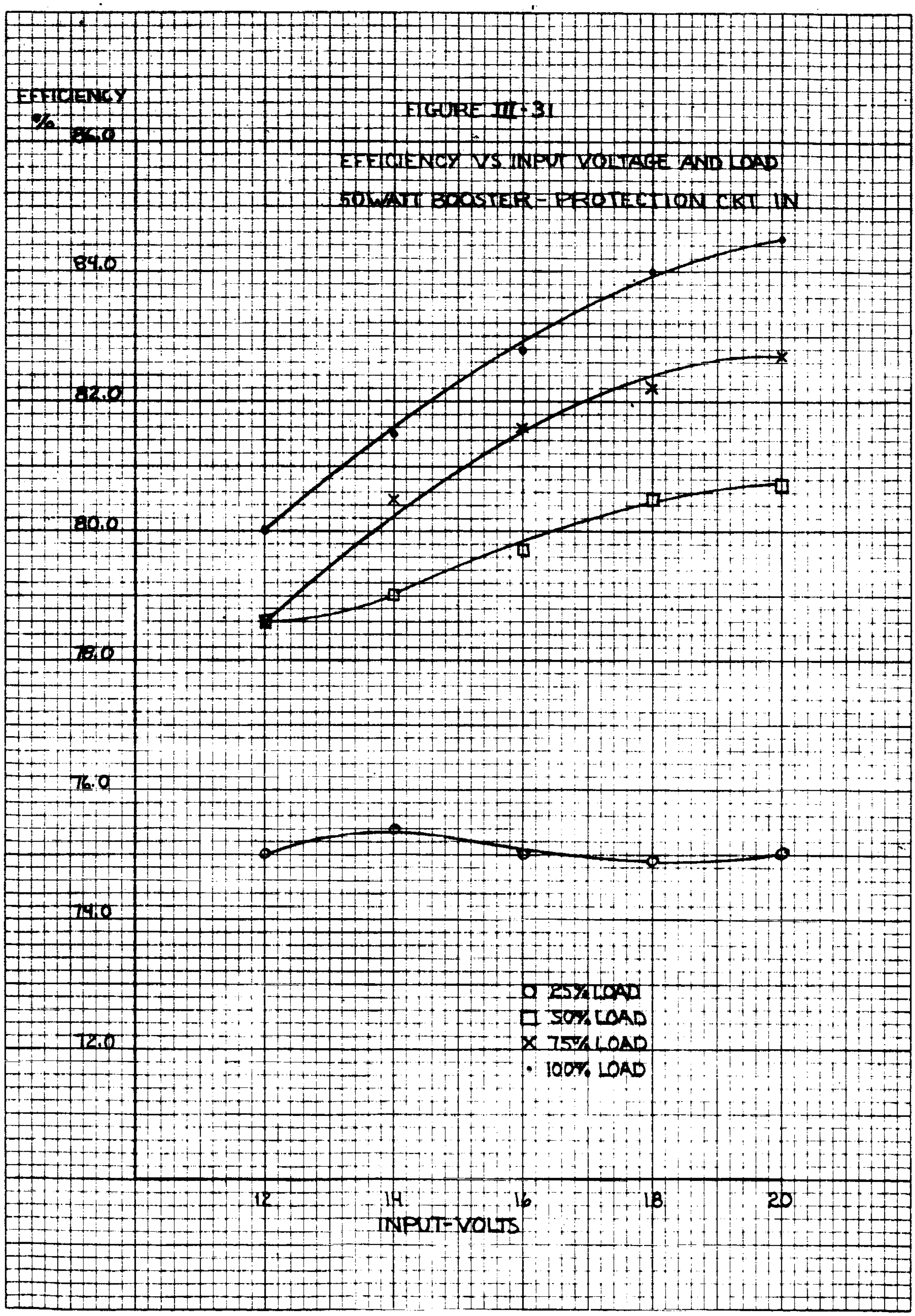


FIGURE III-30
EFFICIENCY VS INPUT VOLTAGE AND LOAD
50 WATT BOOSTER - PROTECTION CKT OUT
EFFICIENCY %
92.0
90.0
88.0
86.0
84.0
82.0
80.0
12
14
16
18
20
INPUT-VOLTS
25% LOAD
50% LOAD
75% LOAD
100% LOAD


EFFICIENCY %
FIGURE III-31
EFFICIENCY VS INPUT VOLTAGE AND LOAD
50WATT BOOSTER - PROTECTION CKT IN
86.0
84.0
82.0
80.0
78.0
76.0
74.0
72.0
○ 25% LOAD
□ 50% LOAD
X 75% LOAD
· 100% LOAD
12
14
16
18
20
INPUT-VOLTS

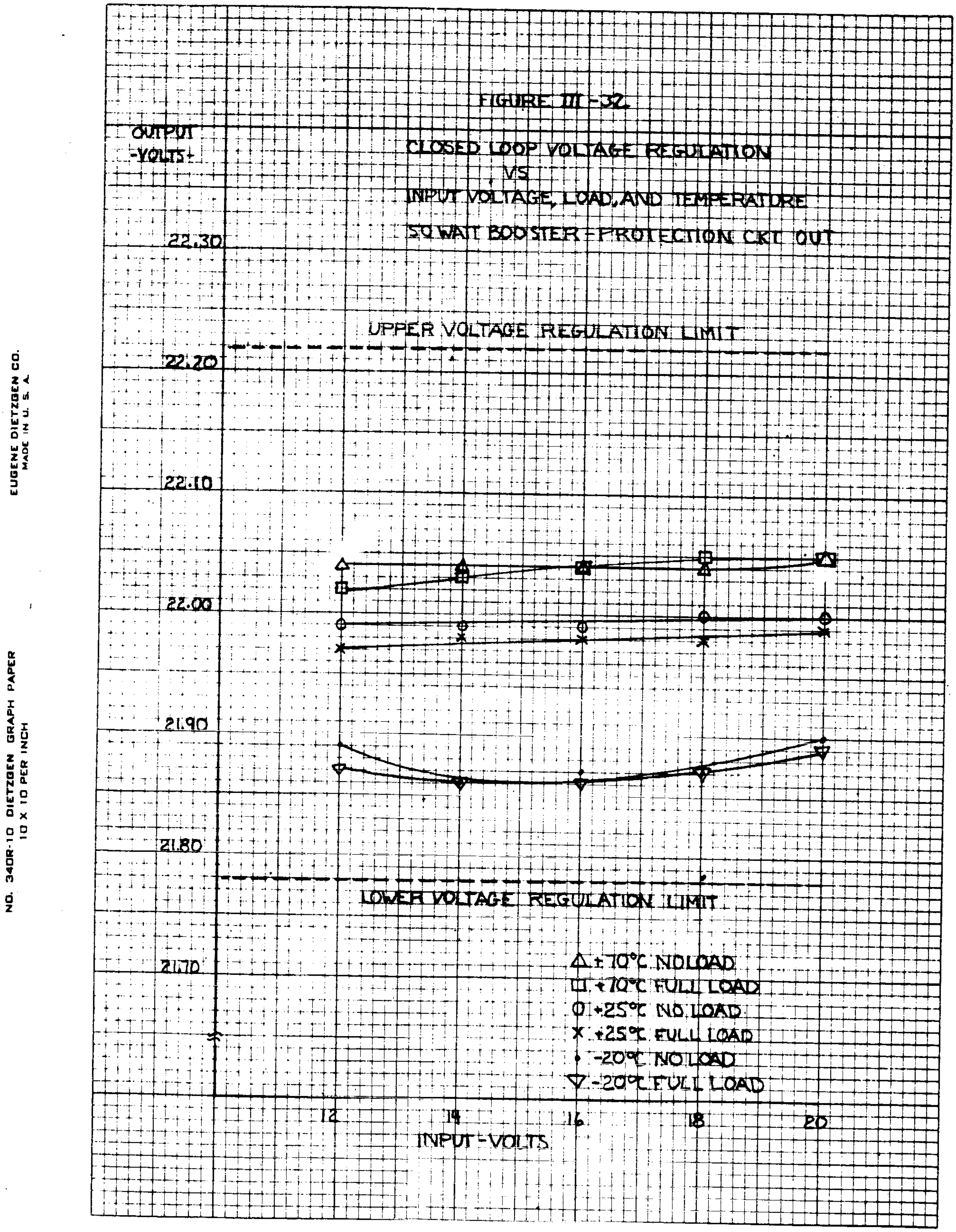


FIGURE III-32.
CLOSED LOOP VOLTAGE REGULATION
VS
INPUT VOLTAGE, LOAD, AND TEMPERATURE
50 WATT BOOSTER - PROTECTION CKT OUT
OUTPUT -VOLTS-
22.30
22.20
22.10
22.00
21.90
21.80
21.70
UPPER VOLTAGE REGULATION LIMIT
LOWER VOLTAGE REGULATION LIMIT
△ +70°C NO LOAD
□ +70°C FULL LOAD
○ +25°C NO LOAD
X +25°C FULL LOAD
• -20°C NO LOAD
▽ -20°C FULL LOAD
12
14
16
18
20
INPUT - VOLTS
NO. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

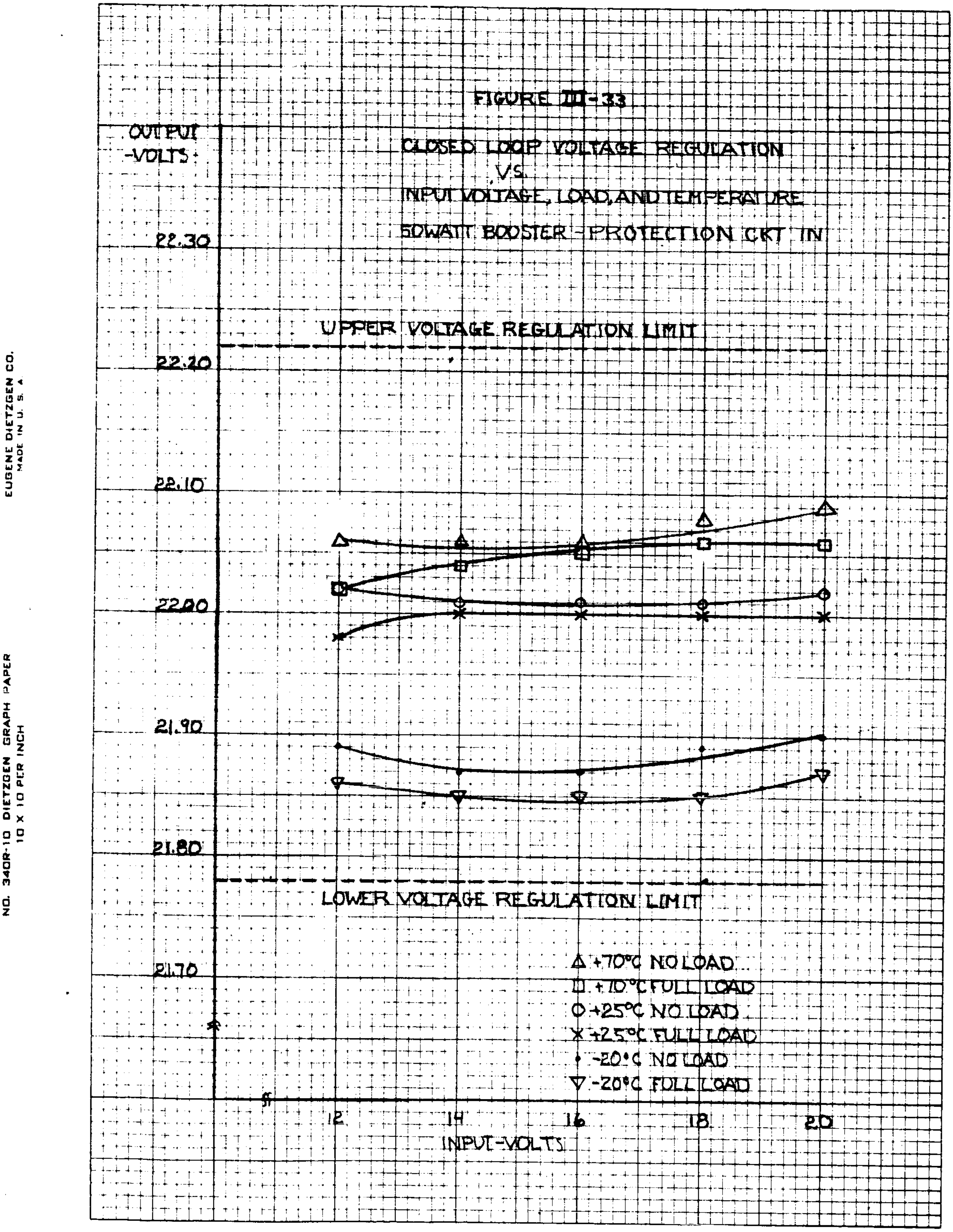
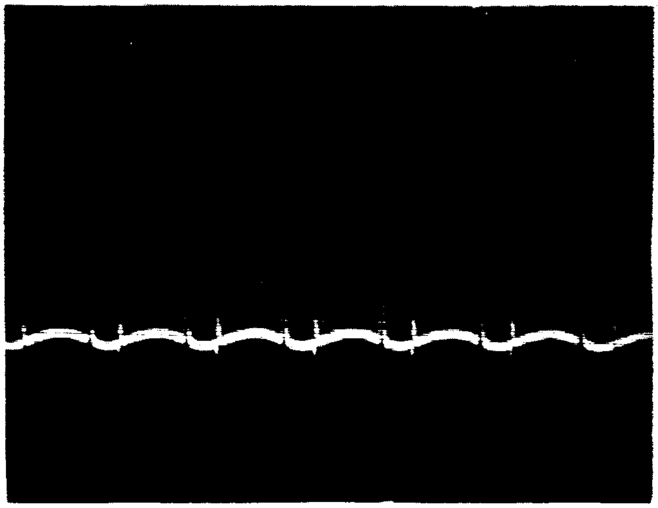
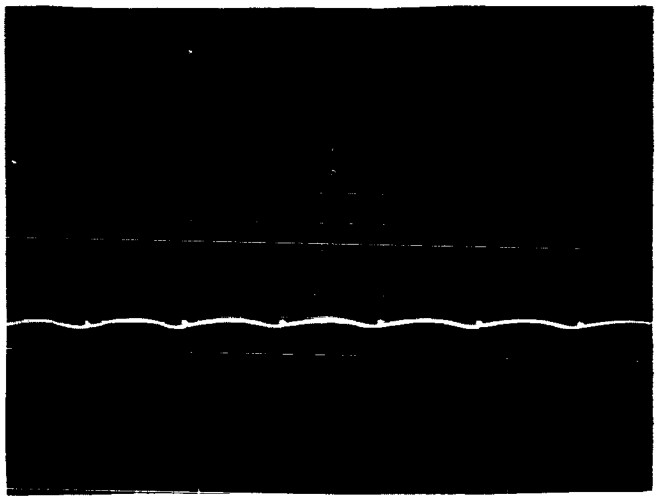


FIGURE III-33
CLOSED LOOP VOLTAGE REGULATION
VS.
INPUT VOLTAGE, LOAD, AND TEMPERATURE
50WATT BOOSTER - PROTECTION CKT IN
OUTPUT -VOLTS
22.30
22.20
22.10
22.00
21.90
21.80
21.70
UPPER VOLTAGE REGULATION LIMIT
LOWER VOLTAGE REGULATION LIMIT
△ +70°C NO LOAD
□ +70°C FULL LOAD
○ +25°C NO LOAD
✕ +25°C FULL LOAD
• -20°C NO LOAD
▽ -20°C FULL LOAD
12
14
16
18
20
INPUT-VOLTS
NO. 340R-10 DIETZGEN GRAPH PAPER 10 X 10 PER INCH
EUGENE DIETZGEN CO. MADE IN U. S. A.

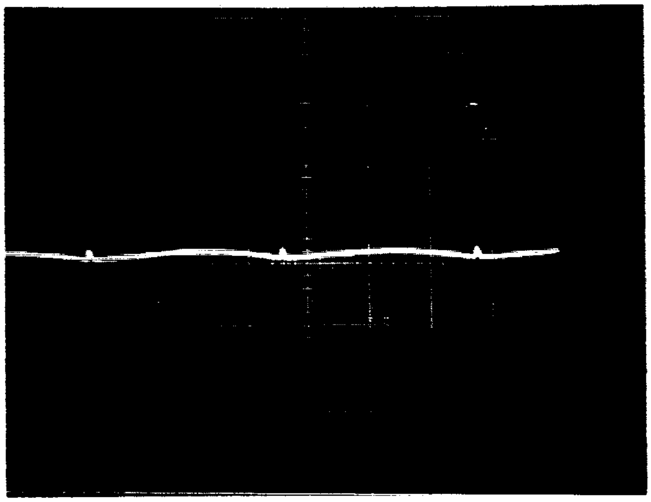


Input Ripple Current No Load 16 Volt Input
Vert. Scale: 95 ma/Div
Horz. Scale 20 μsec/Div

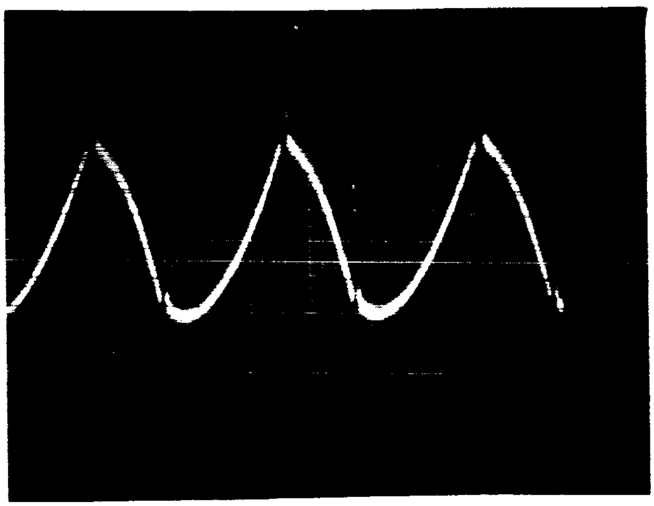


Input Ripple Current Full Load 16 Volt Input
Vert. Scale: 95 ma/Div
Horz. Scale: 20 μsec/Div

Figure III-34 Input Ripple Current 50 Watt Booster

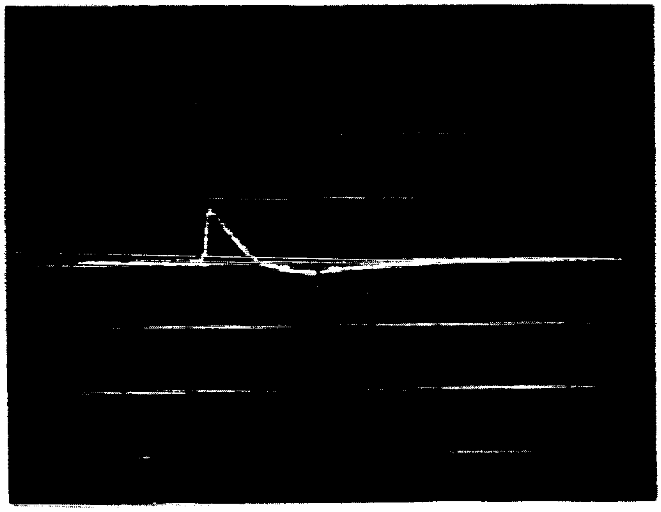


Output Ripple Voltage No Load 16 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

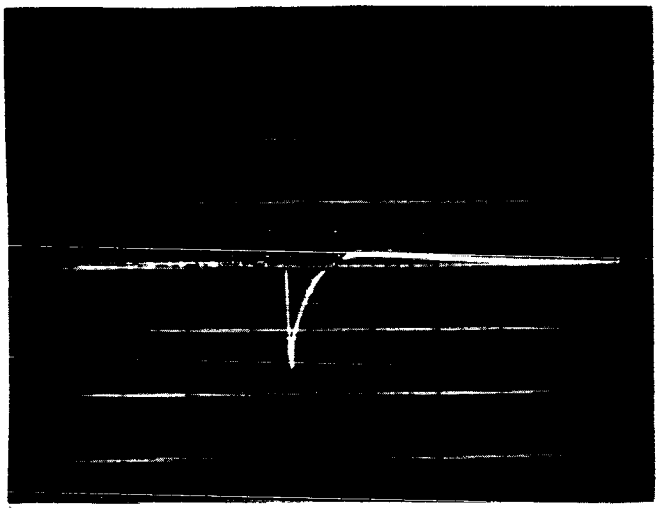


Output Ripple Voltage Full Load 16 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

Figure III-35 Output Ripple Voltage 50 Watt Booster

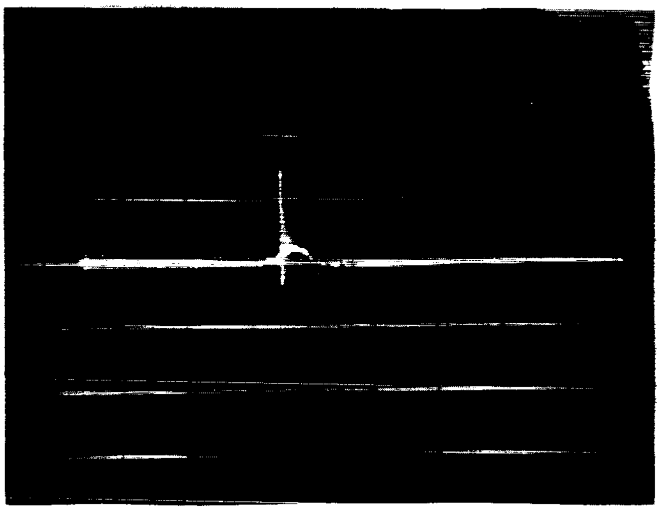


12 To 20 Volts Input At No Load Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale .1 Sec/Div.

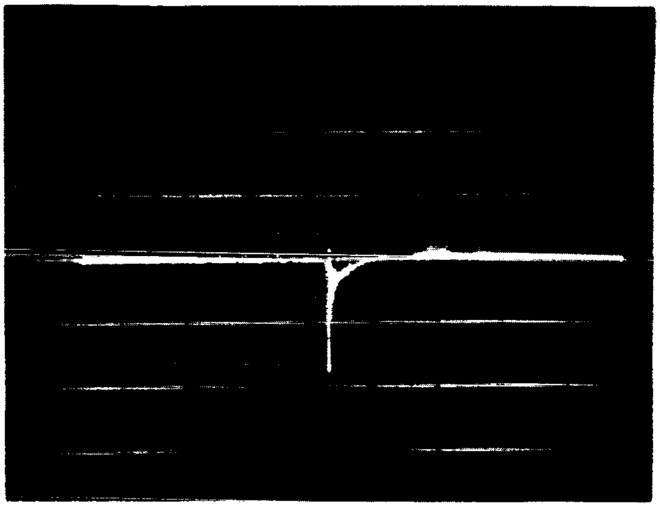


20 To 12 Volts Input At No Load Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-36 Dynamic Response 50 Watt Booster

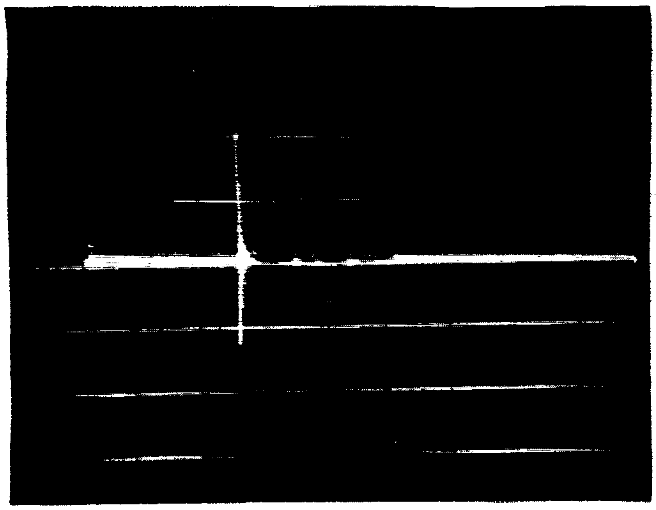


12 To 20 Volts Input At Full Load Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

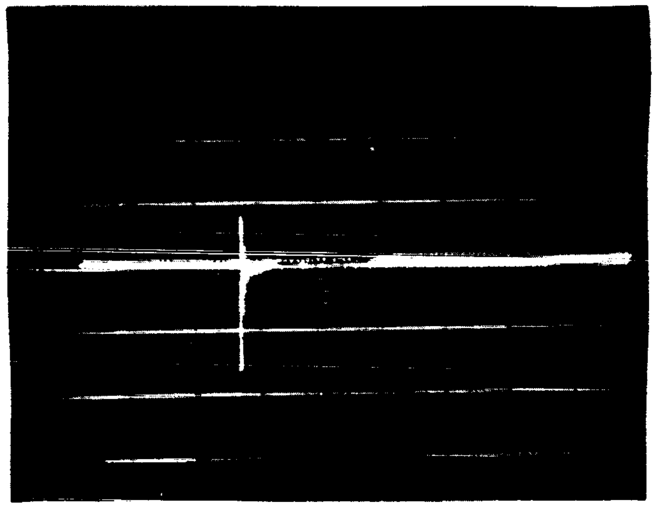


20 To 12 Volts Input At Full Load Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-37 Dynamic Response 50 Watt Booster

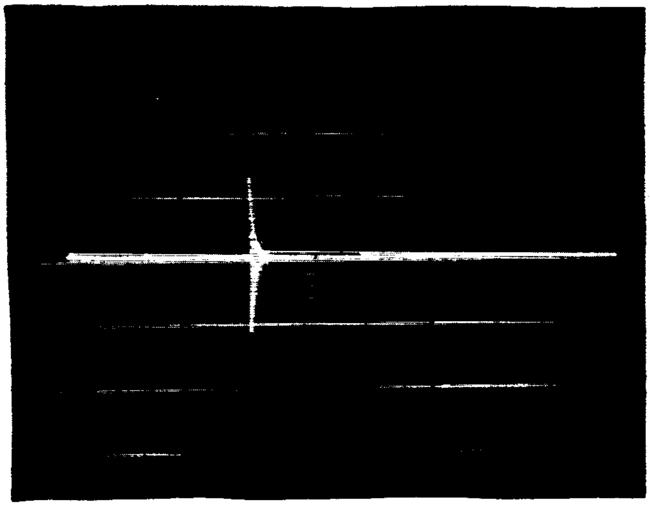


Full Load to 3/4 At 12 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

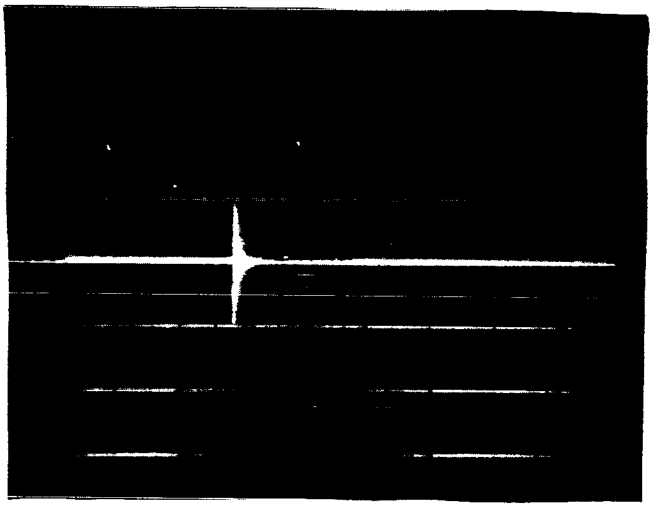


3/4 To Full Load At 12 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 V/Div.

Figure III-38 Dynamic Response 50 Watt Booster

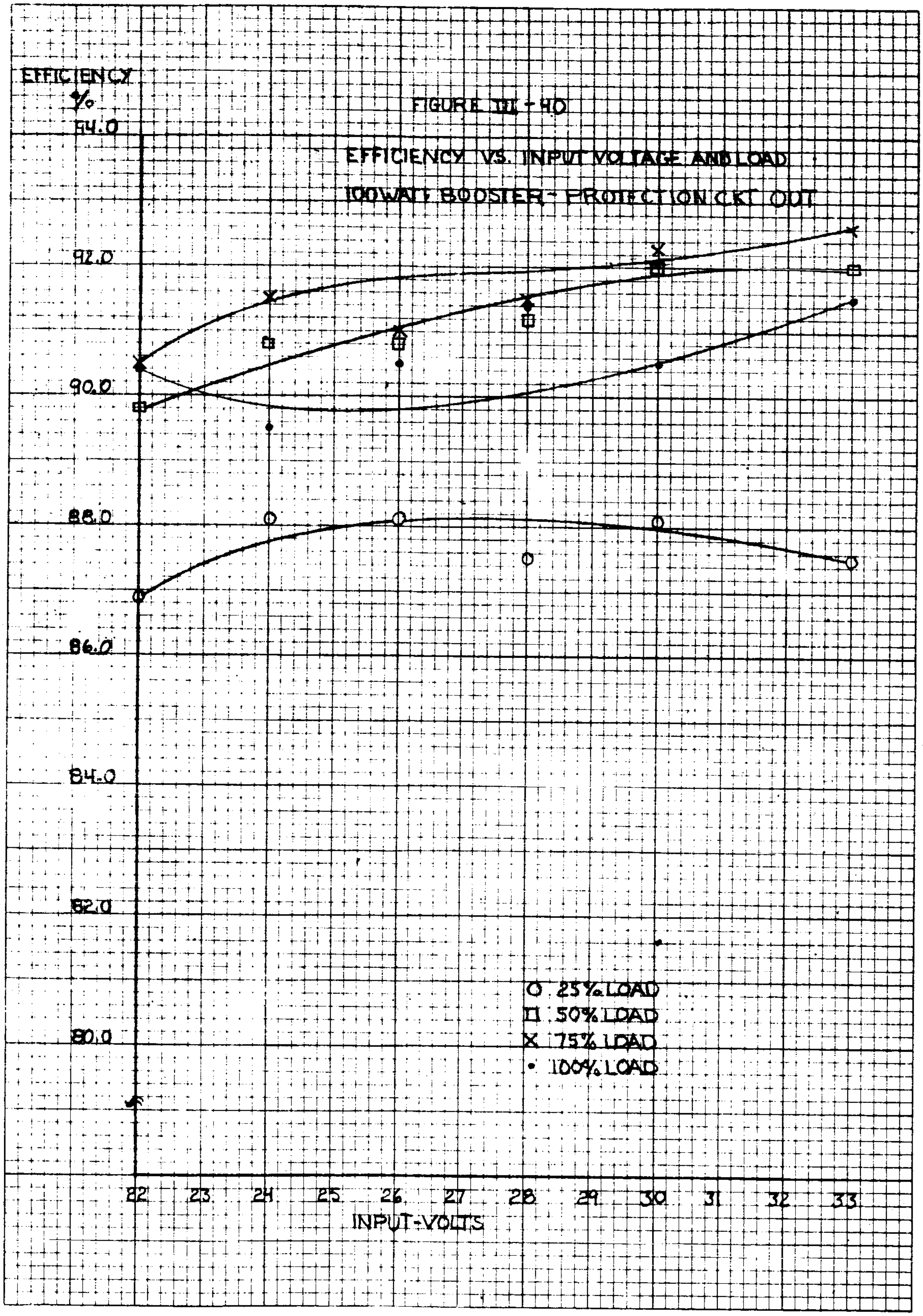


Full Load To 3/4 At 20 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div
Horizontal Scale .1 Sec/Div.



3/4 To Full Load At 20 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-39 Dynamic Response 50 Watt Booster



NO. 340R-10 DIETZGEN GRAPH PAPER 10 X 10 PER INCH

EUGENE DIETZGEN CO. MADE IN U. S. A.

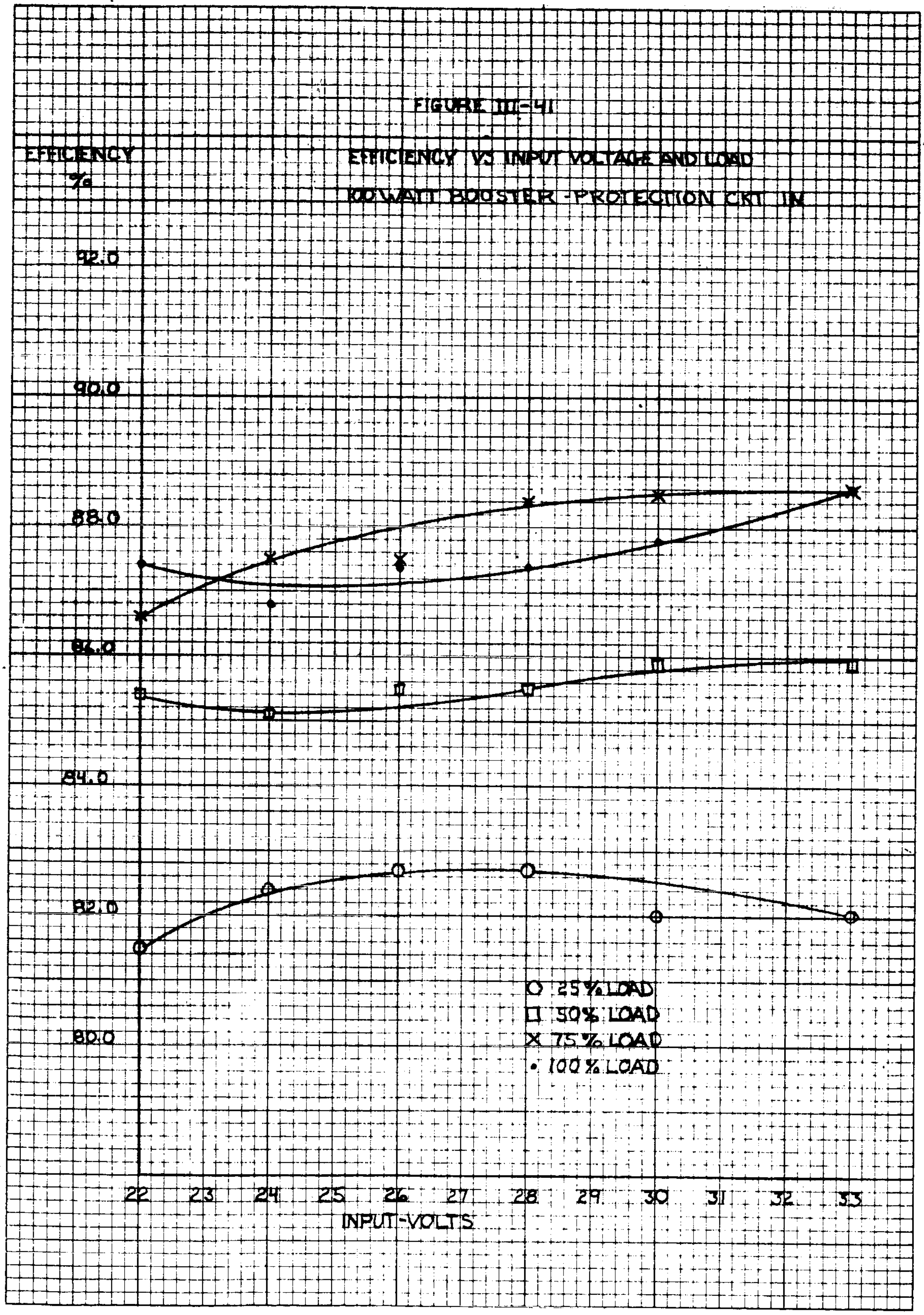
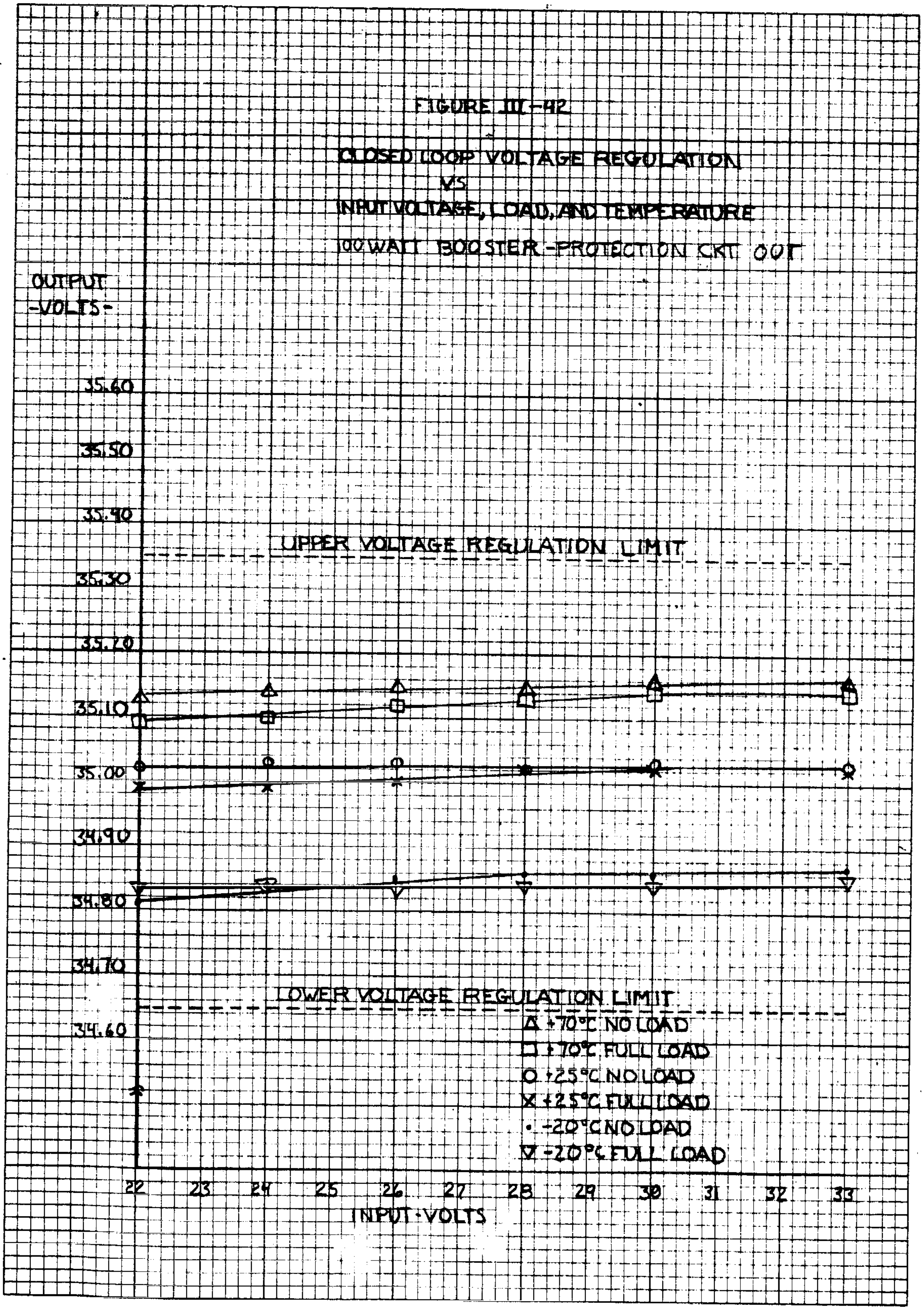


FIGURE III-41
EFFICIENCY VS INPUT VOLTAGE AND LOAD
100 WATT BOOSTER - PROTECTION CKT IN
EFFICIENCY %
92.0
90.0
88.0
86.0
84.0
82.0
80.0
22
23
24
25
26
27
28
29
30
31
32
33
INPUT-VOLTS
○ 25% LOAD
□ 50% LOAD
X 75% LOAD
• 100% LOAD



EUGENE DIETZGEN CO. MADE IN U. S. A.

NO. 340R-10 DIETZGEN GRAPH PAPER 10 X 10 PER INCH

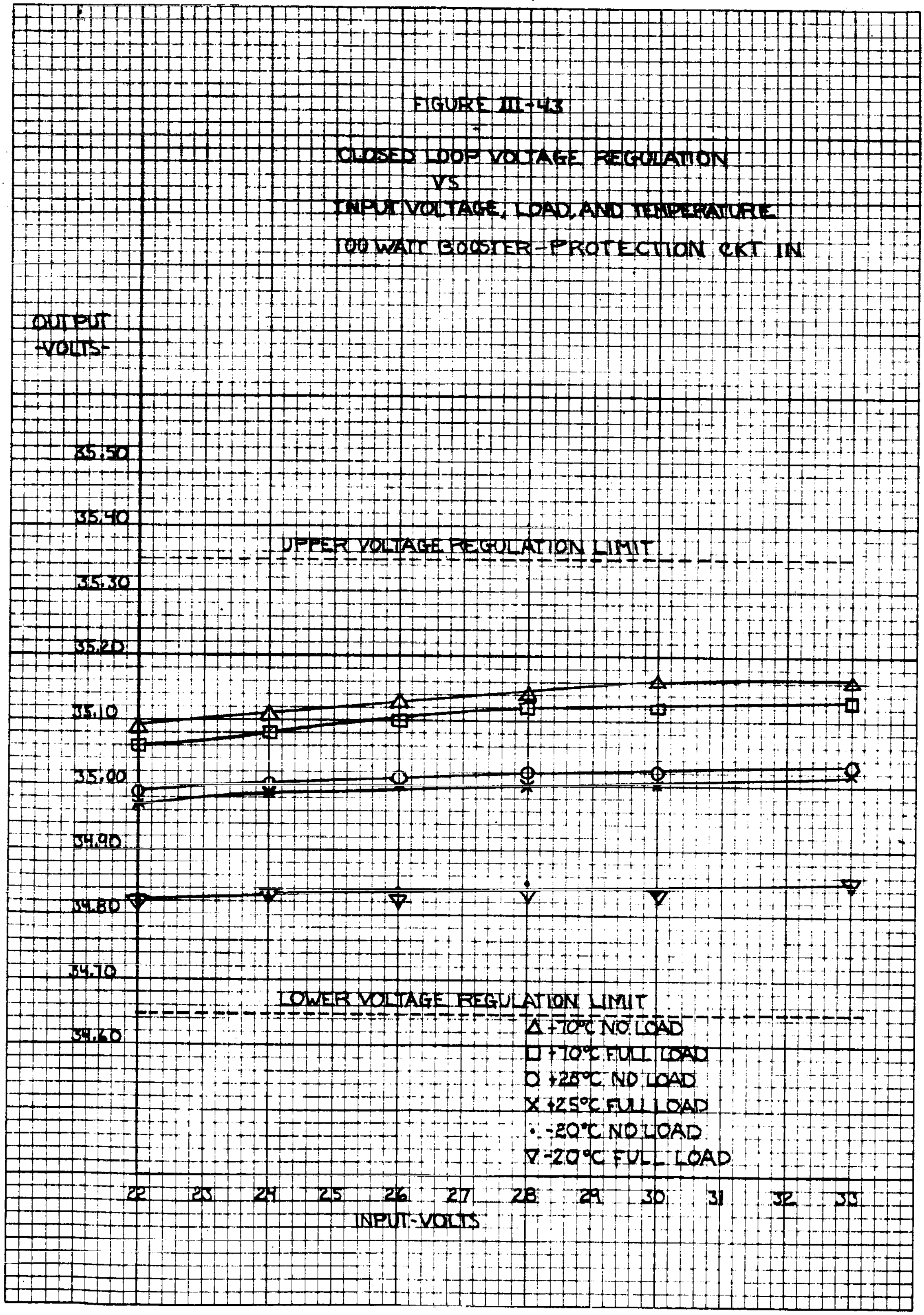
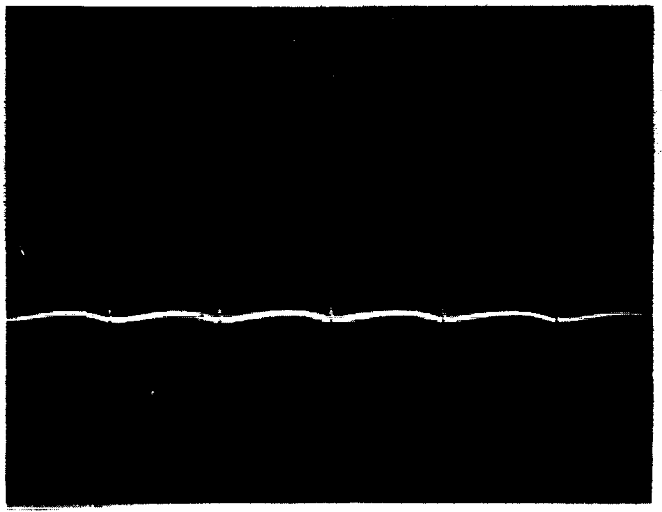
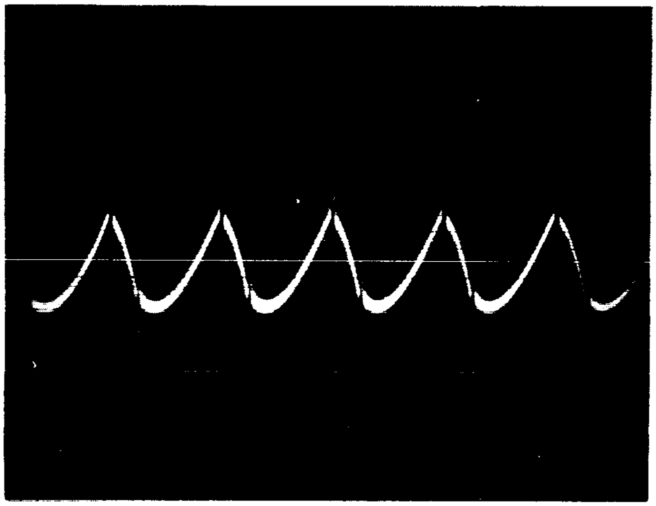


FIGURE III-43
CLOSED LOOP VOLTAGE REGULATION
VS
INPUT VOLTAGE, LOAD, AND TEMPERATURE
100 WATT BOOSTER-PROTECTION CKT IN
OUTPUT
-VOLTS-
35.50
35.40
UPPER VOLTAGE REGULATION LIMIT
35.30
35.20
35.10
35.00
34.90
34.80
34.70
LOWER VOLTAGE REGULATION LIMIT
34.60
Δ +70°C NO LOAD
□ +70°C FULL LOAD
O +25°C NO LOAD
X +25°C FULL LOAD
• -20°C NO LOAD
∇ -20°C FULL LOAD
22
23
24
25
26
27
28
29
30
31
32
33
INPUT-VOLTS

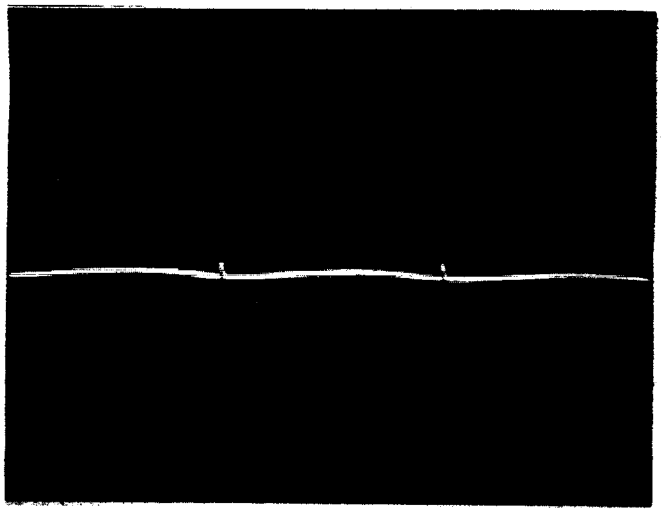


Input Ripple Current No Load 27.5 Volt Input
Vert. Scale 95 ma/Div
Horz. Scale: 20 μsec/Div

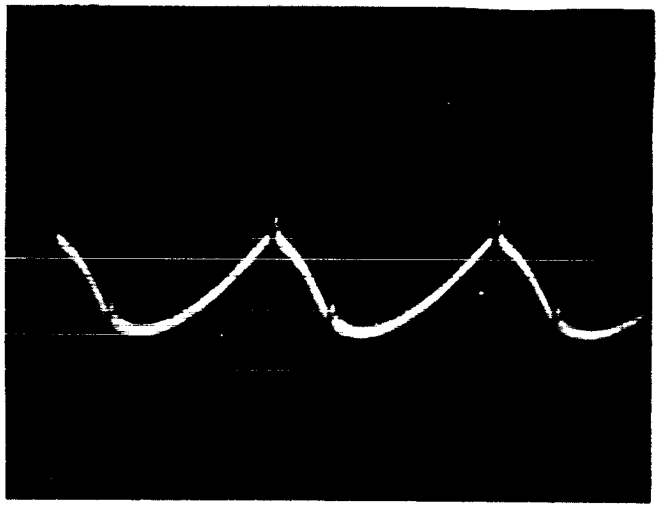


Input Ripple Current Full Load 27.5 Volt Input
Vert. Scale: 95 ma/Div
Horz. Scale: 20 μsec/Div

Figure III-44 Input Ripple Current 100 Watt Booster



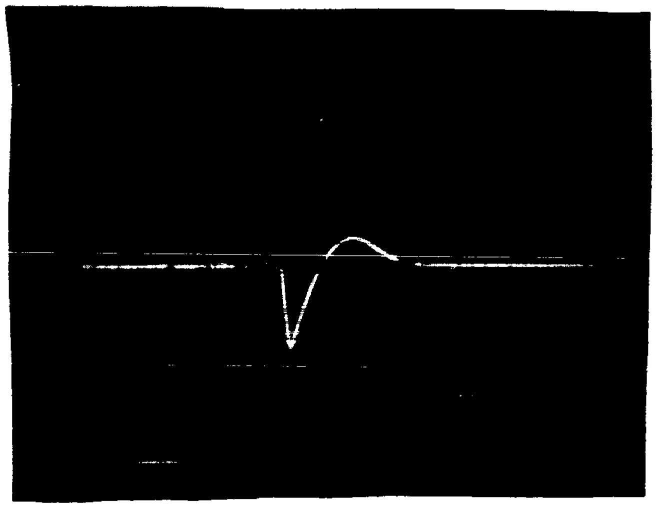
Output Ripple Voltage No Load 27.5 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div



Output Ripple Voltage Full Load 27.5 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

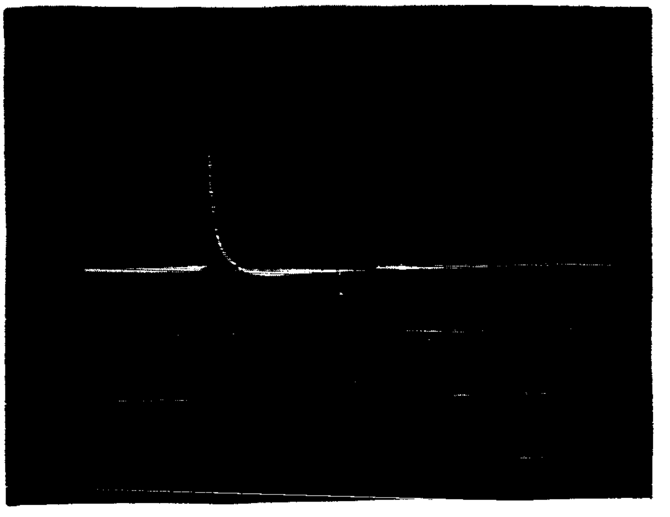
Figure III-45 Output Ripple Voltage 100 Watt Booster

22 To 33 Volts Input At No Load Output
Voltage Transient
Vertical Scale 1.0 V/Div.
Horizontal Scale .1 Sec/Div.

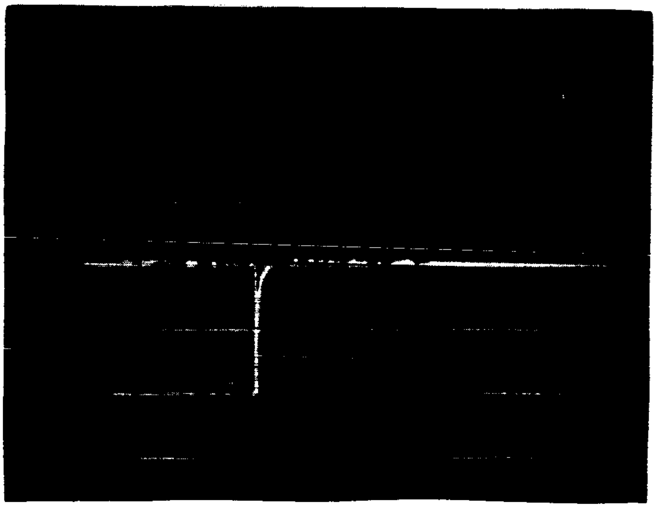


33 To 22 Volts Input At No Load Output
Voltage Transient
Vertical Scale 1.0 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III=46 Dynamic Response 100 Watt Booster

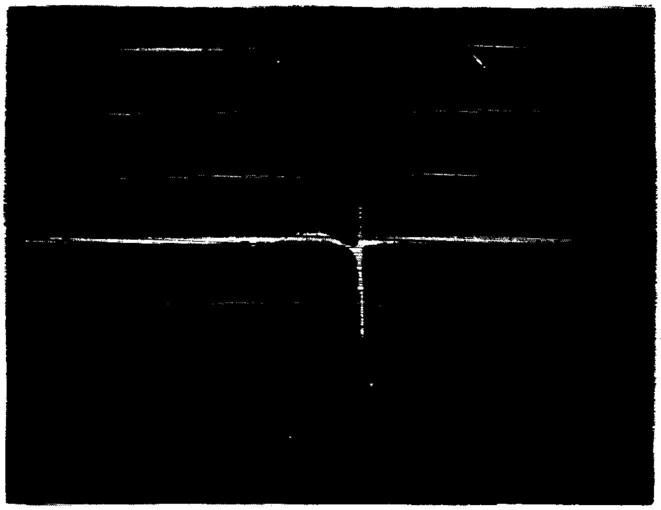


22 To 33 Volts Input At Full Load Output
Voltage Transient
Vertical Scale .5V/Div.
Horizontal Scale .1 V/Div.

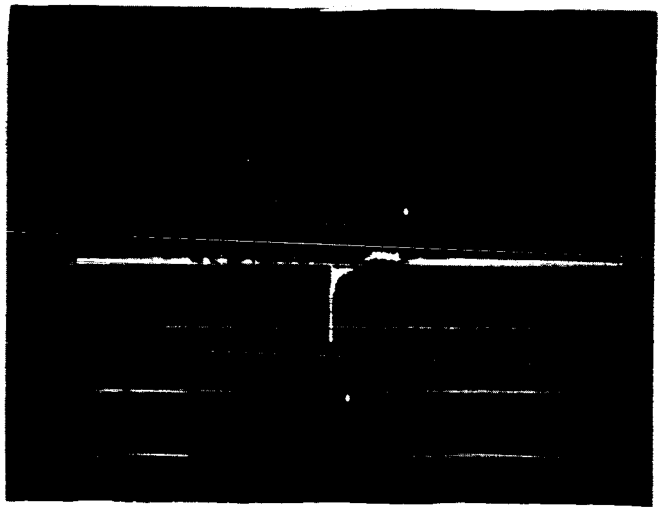


33 To 22 Volts Input At Full Load Output
Voltage Transient
Vertical Scale 2.0 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-47 Dynamic Response 100 Watt Booster

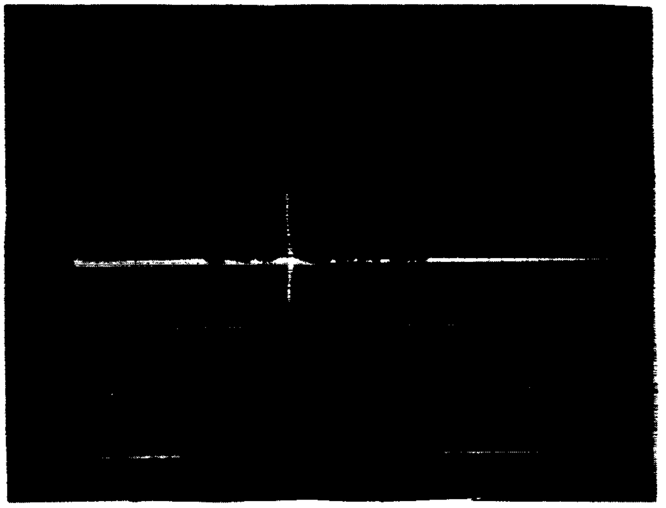


Full Load To 3/4 At 22 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

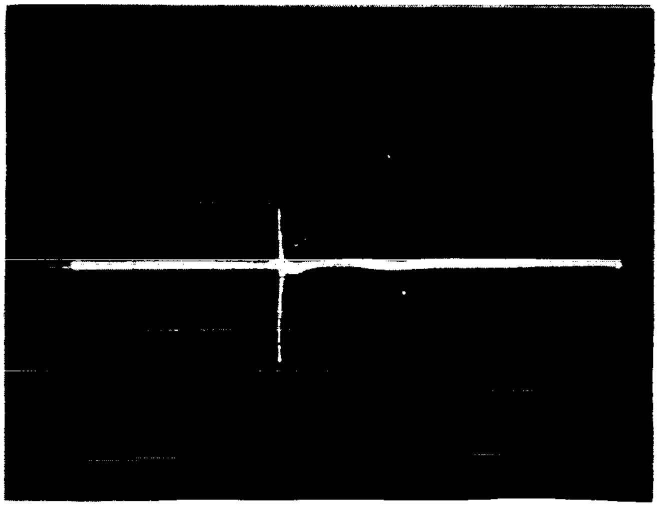


3/4 To Full Load At 22 Volts In Output
Voltage Transient
Vertical Scale .5 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-48 Dynamic Response 100 Watt Booster



Full Load to 3/4 At 33 Volts In Output
Voltage Transient
Vertical Scale .5V/Div.
Horizontal Scale .1 Sec/Div.



3/4 To Full Load At 33 Volts In Output
Voltage Transient
Vertical Scale .2 V/Div.
Horizontal Scale .1 Sec/Div.

Figure III-49 Dynamic Response 100 Watt Booster

APPENDIX IV

Breadboard Test Data
Chopper Regulator Converters

CHOPPER PERFORMANCE CHARACTERISTICS

The following tests were run on the Phase II chopper breadboards to determine their performance characteristics:

1. No load losses
2. Efficiency
3. Open loop regulation
4. Output voltage ripple
5. Input current ripple

The no load losses test was run with a digital voltmeter directly at the input terminals of the chopper, and an ammeter between the voltmeter and the power source. Power was calculated as the volt ampere product.

The efficiency was run with digital voltmeters directly across the input and output terminals of the chopper and ammeter between the input voltmeter and the power source and between the output voltmeter and the board. Efficiency was calculated as $(V_{out}I_{out}/V_{in}I_{in}) \times 100$. No measurement was made of power supplied by the auxiliary B+ supply used to operate the control circuitry in the open loop mode.

Open loop regulation was measured with a digital voltmeter directly across the input and output terminals. The output was set to nominal at low line full load and not reset for the duration of the test.

Output voltage ripple was measured on a 561A Tektronix oscilloscope across the output. Only ripple below 1 mc was recorded.

Input current ripple was measured with a 561A Tektronix oscilloscope across a .105 ohm resistor in series with the input supply line.

CHOPPER DATA ANALYSIS

I. No Load Losses:

The no load losses of the choppers are approximately proportional to the power level of the boards because a large portion of these losses is due to external bleeders and these bleeders are sized for each power level. The relatively large increase in 100 watt losses indicates losses in the reset circuit and power diode, as these conduct more as input voltage increases the 10, 25, and 50 watt choppers have no load losses of about .7, 1.3, and 2.3 watts respectively; the 100 watt losses vary from 4.8 to 8.4 watts.

II. Efficiency:

Efficiency measurements were taken on all the choppers at 1/4, 1/2, 3.4, and full load over the input voltage range. The data shown a decrease in efficiency as the input voltage increases indicating that a large portion of the losses are in the power diode and reset circuitry. The peak efficiencies for the 10, 25, 50 and 100 watt choppers are 94.3%, 94.5%, 94.5% and 97.9% respectively; the minimum are 86.4, 85.5, 86.4, and 92.4%. These efficiencies do no include losses in circuitry powered by auxiliary supplies or bleeder resistors.

III. Static Regulation - Open Loop:

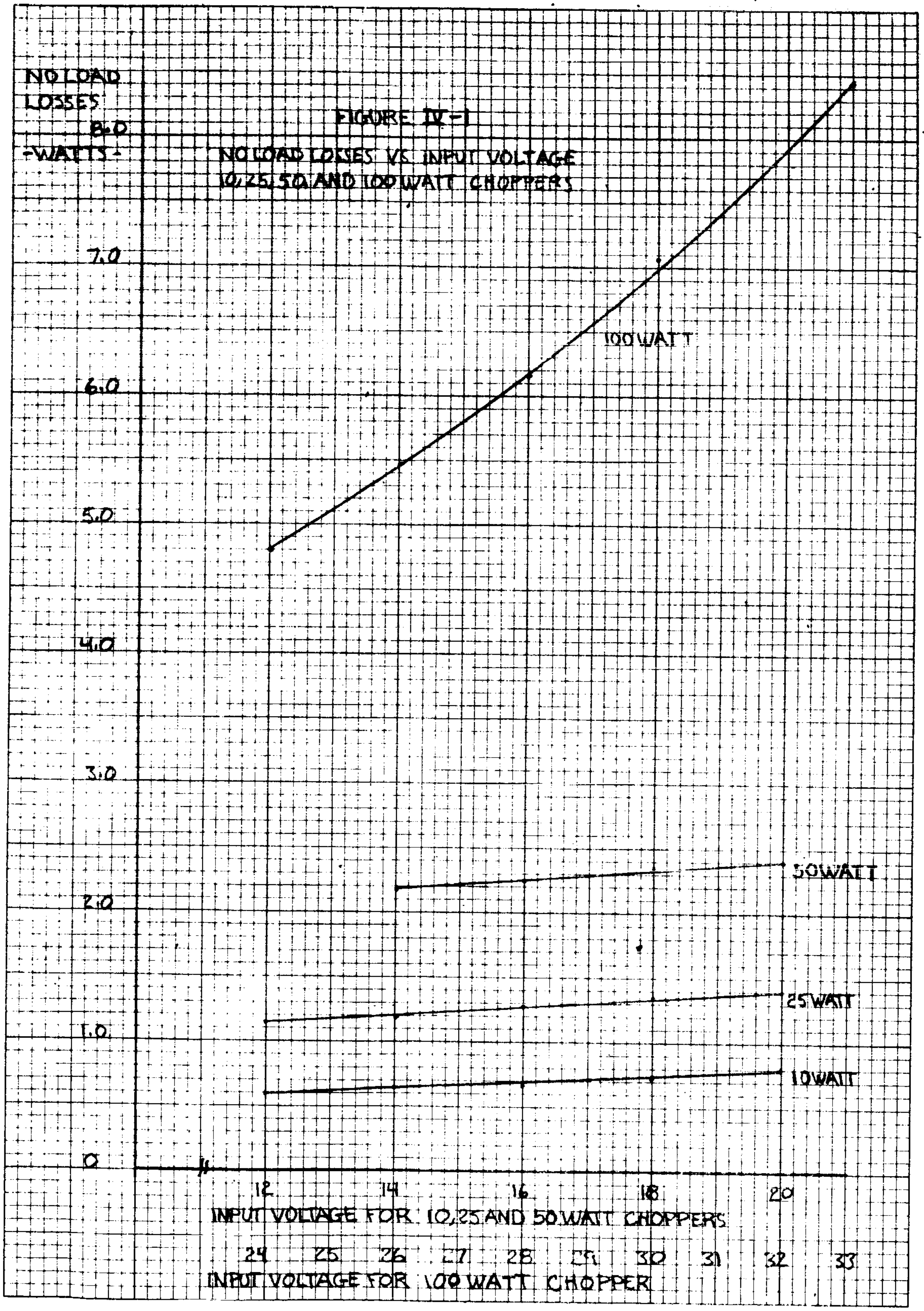
For this test, the output voltage was set at its nominal value at full load, low line, and the input voltage was varied over the specified range for no load, 1/4, 1/2, 3/4, and full load. The resulting output voltage regulation indicates that output voltage increases with input voltage at about 1/2 the rate. (i.e., for a change of 8 volts on the input, the output changes about 4 volts.) The output voltage also decreases as load is increased. The total voltage change on the 10, 25, 50 and 100 watt choppers for line and load variations are 3.8V, 5.3V, 6.4V, and 6.3V respectively.

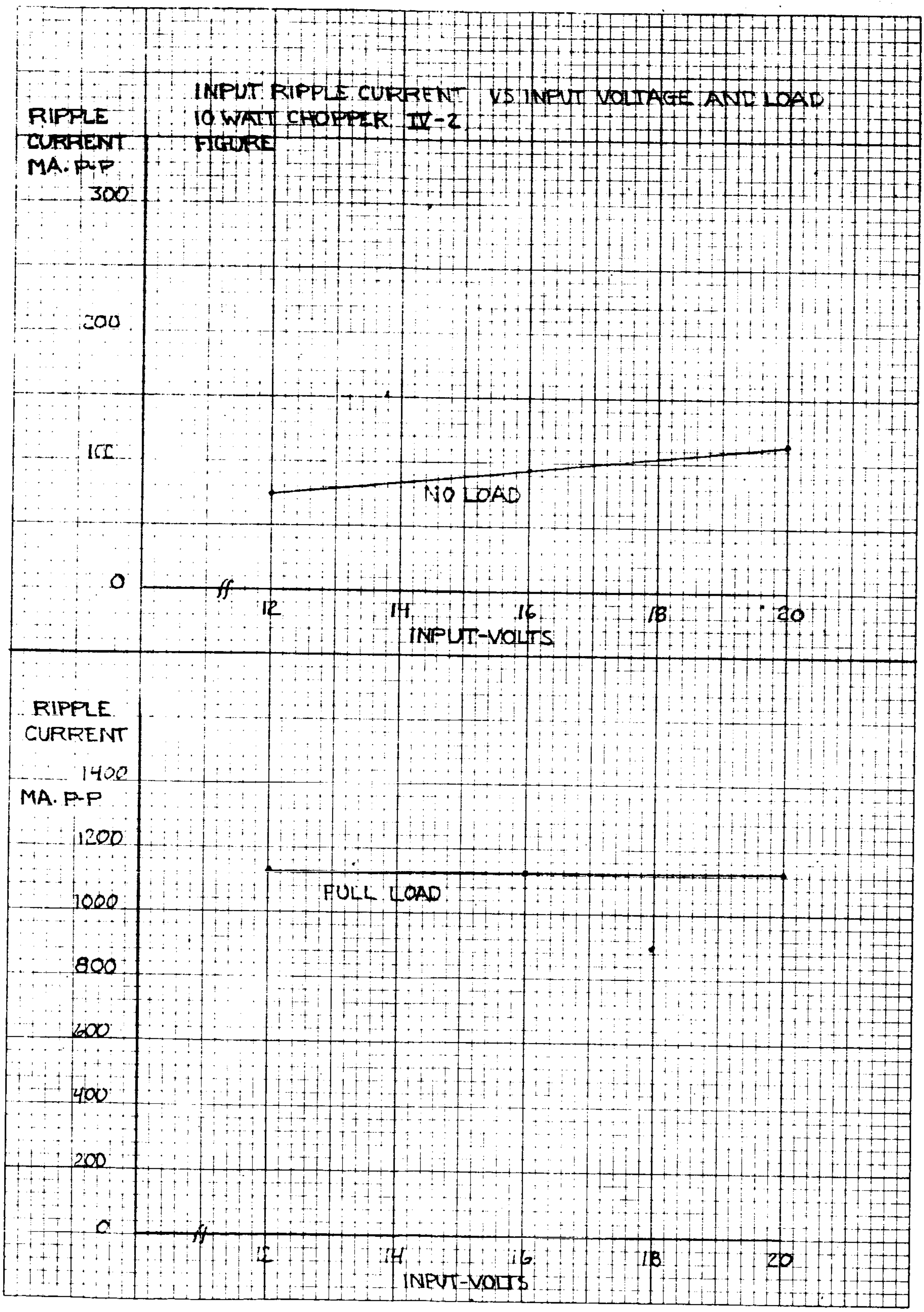
IV. Output Voltage Ripple:

Output ripple was measured at low, mid, and high line at no load and full load. As has been explained previously, only the ripple below 1 mc was recorded. No attempt has been made to finalize output filters, so the ripple data varies radically from unit to unit. The 10, 25, 50 and 100 watt choppers have peak ripple values of 12, 18, 11.5 and 125 mv respectively, thus only the 100 watt unit is out of spec and this could be corrected by switching capacitor types and/or adding an output choke.

V. Input Ripple Current:

Input ripple was measured at low, mid and high line at no load and full load. The unfiltered input ripple to a chopper is inherently high and this is demonstrated in the data. The 10, 25, 50 and 100 watt choppers have input ripple of 1.1, 2.4, 4.2 and 5.7 amps peak to peak respectively; this data was taken with no input filter at all, but indicates that considerable input filtration may be required.


NO LOAD LOSSES -WATTS-
FIGURE IV-1
NO LOAD LOSSES VS. INPUT VOLTAGE
10,25,50 AND 100 WATT CHOPPERS
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
100 WATT
50 WATT
25 WATT
10 WATT
12
14
16
18
20
INPUT VOLTAGE FOR 10,25 AND 50 WATT CHOPPERS
24
25
26
27
28
29
30
31
32
33
INPUT VOLTAGE FOR 100 WATT CHOPPER



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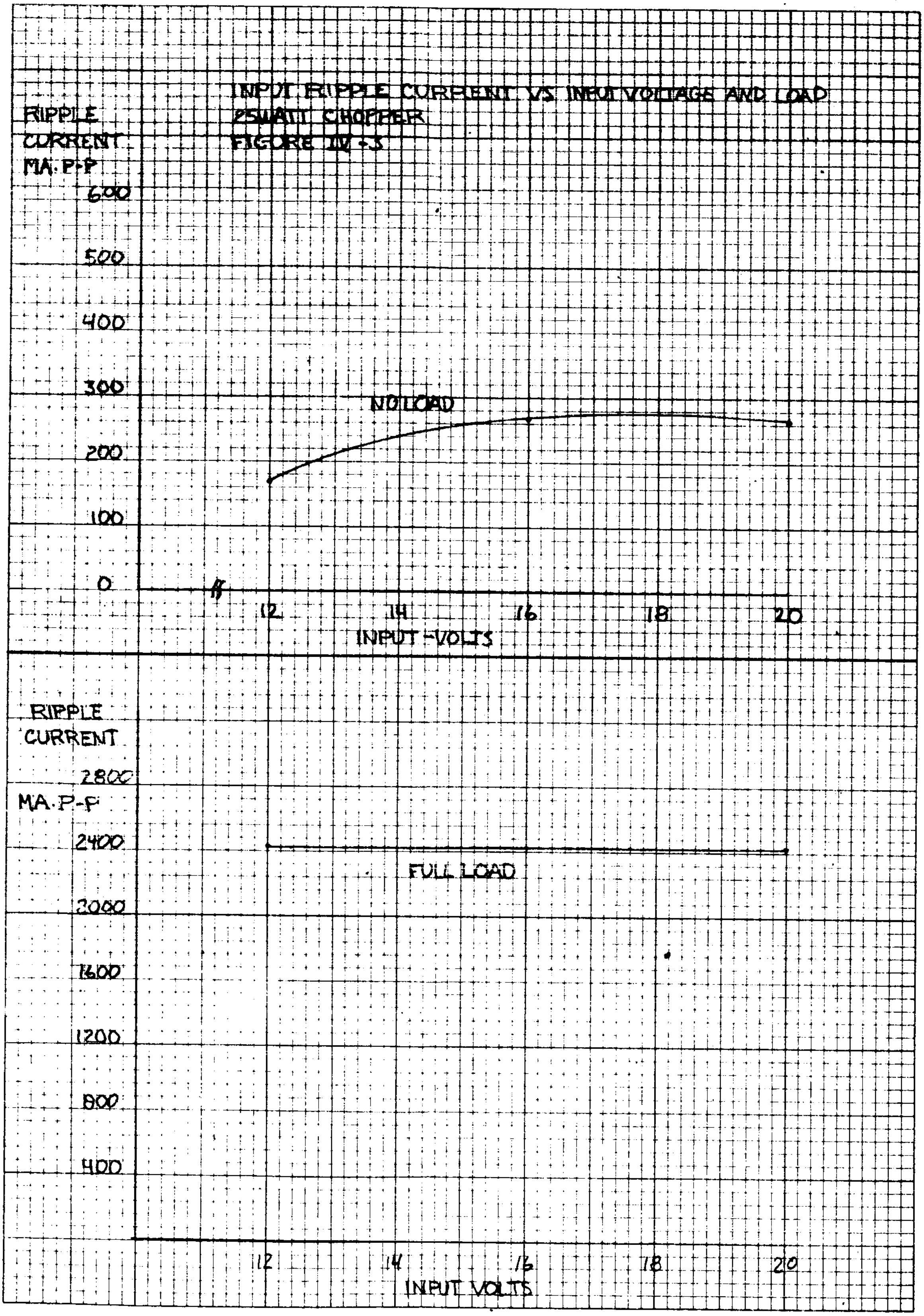
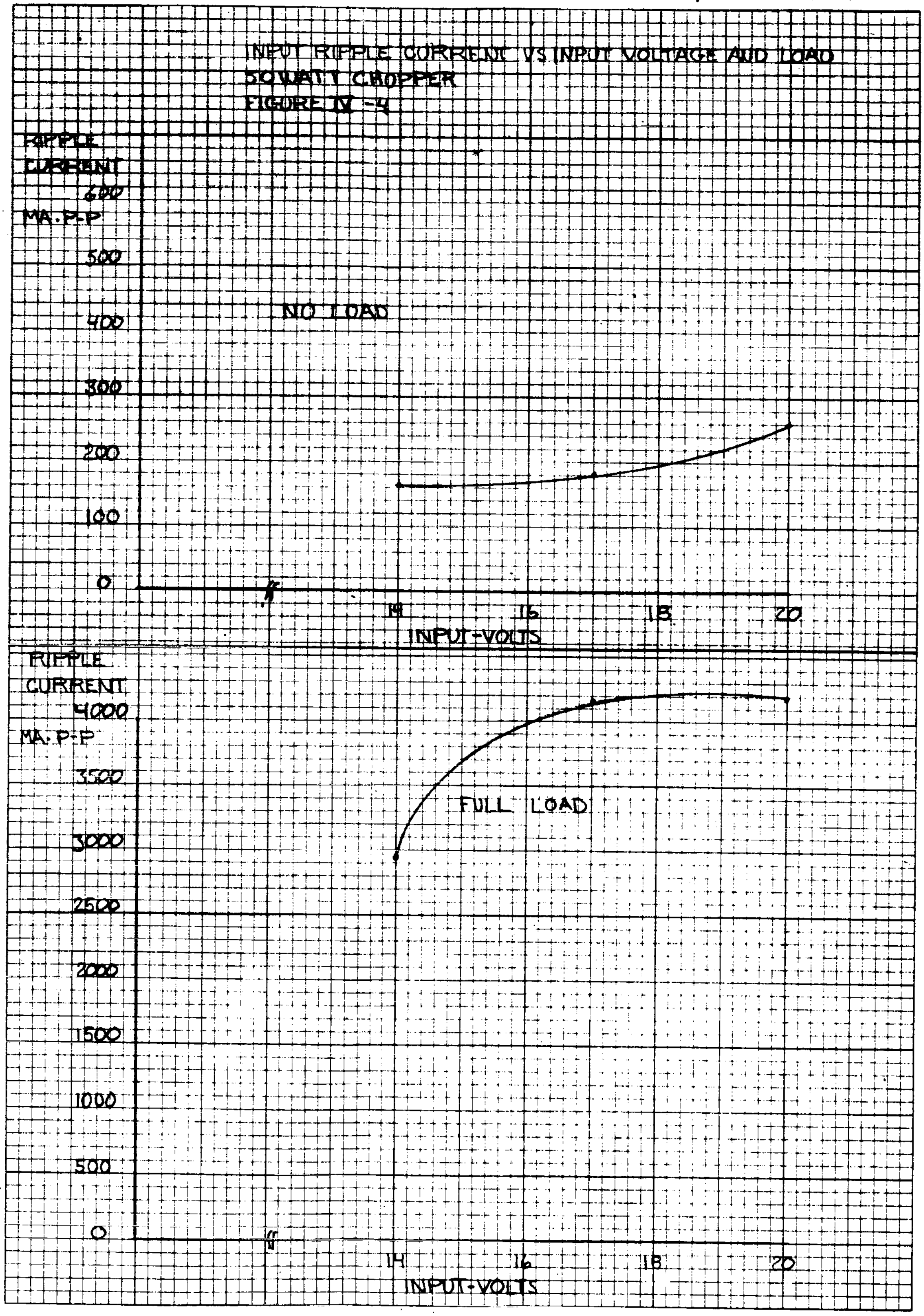
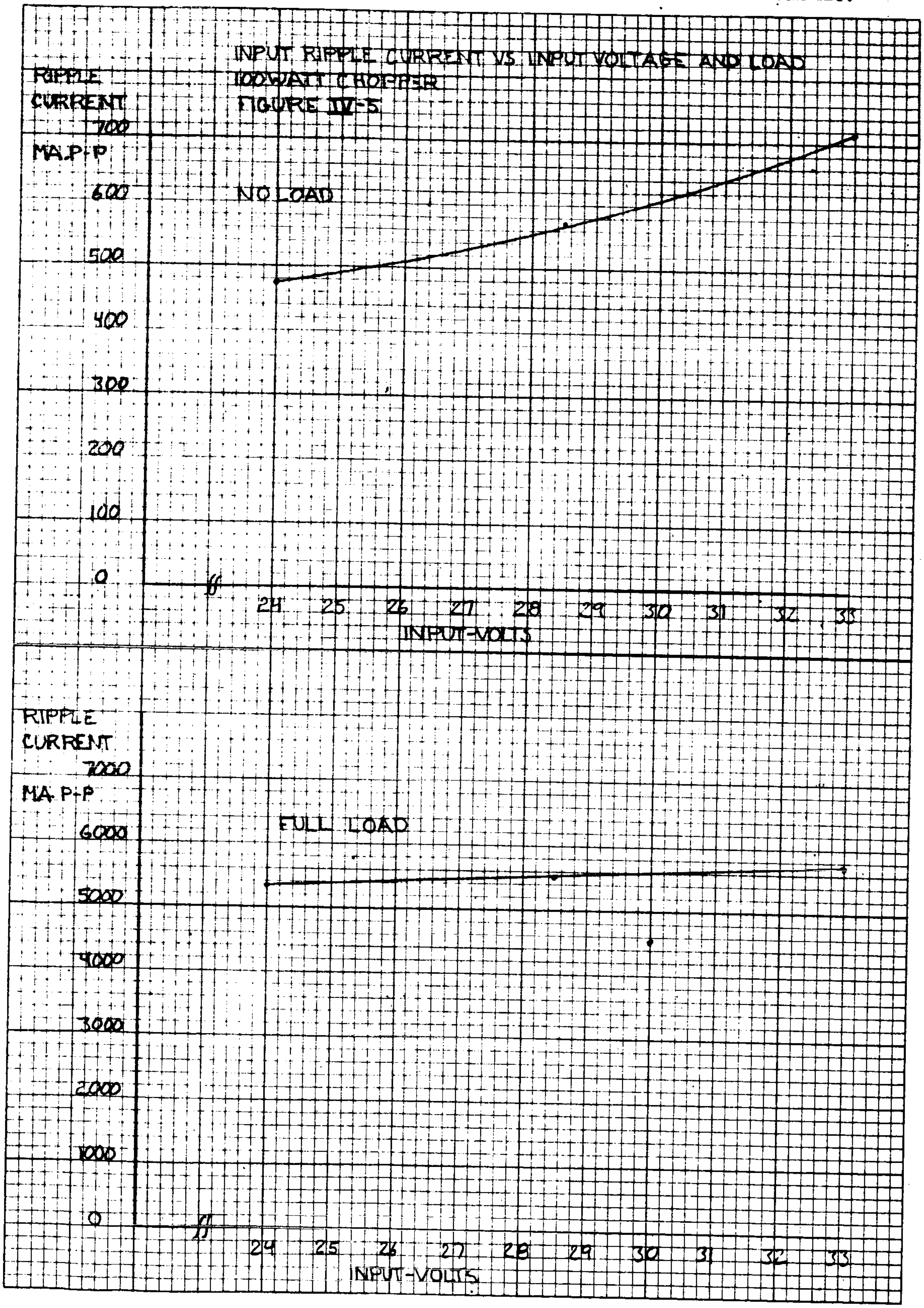
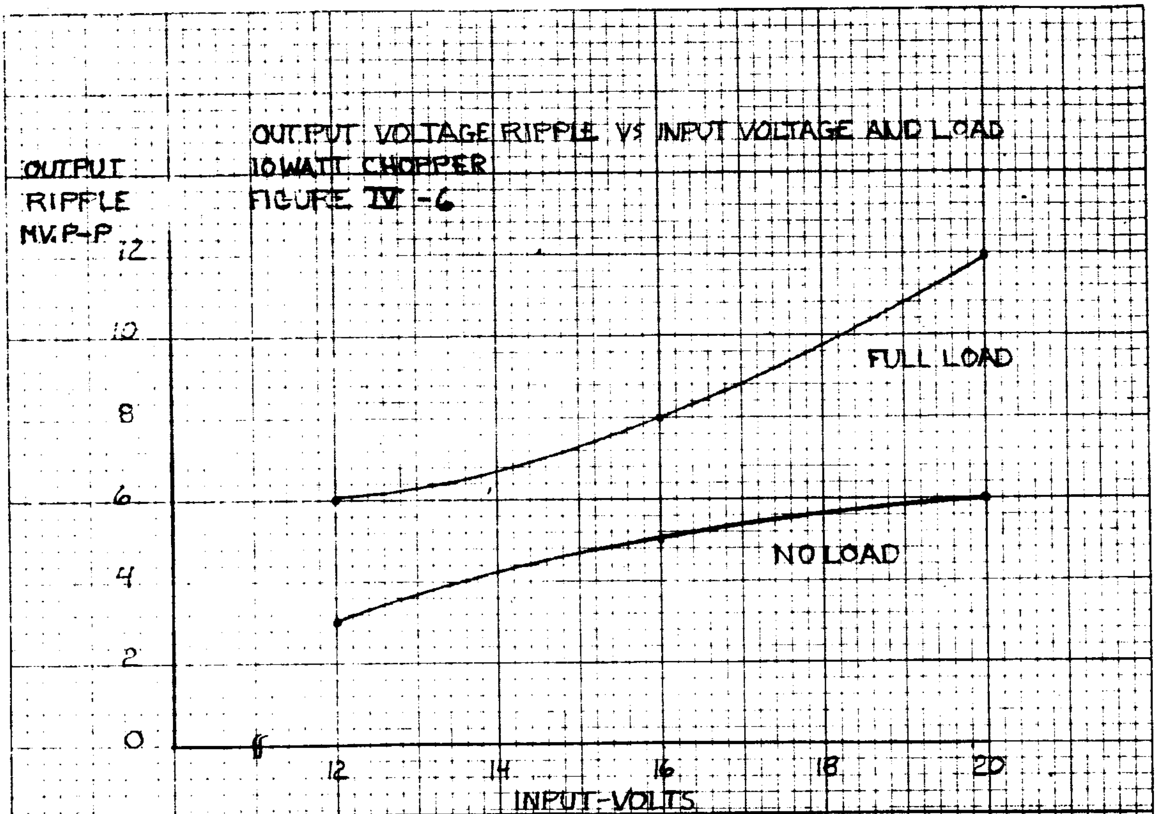
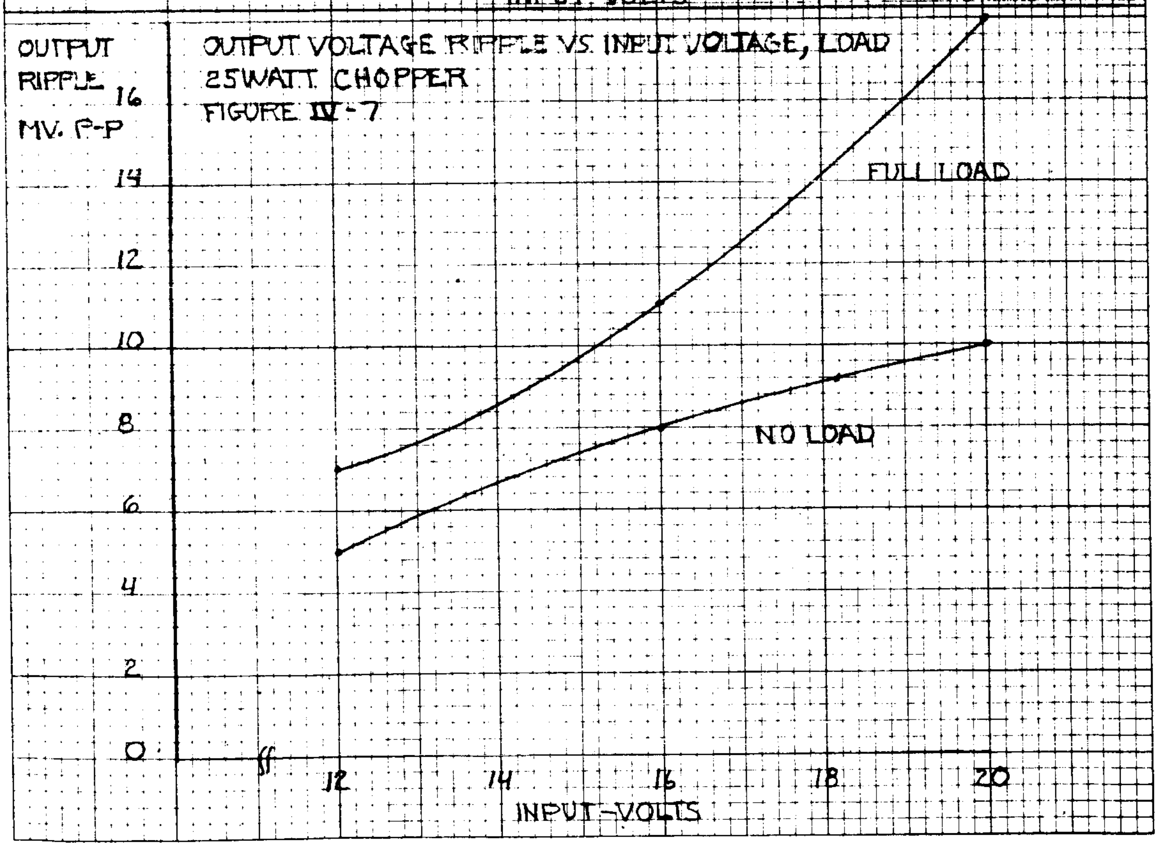
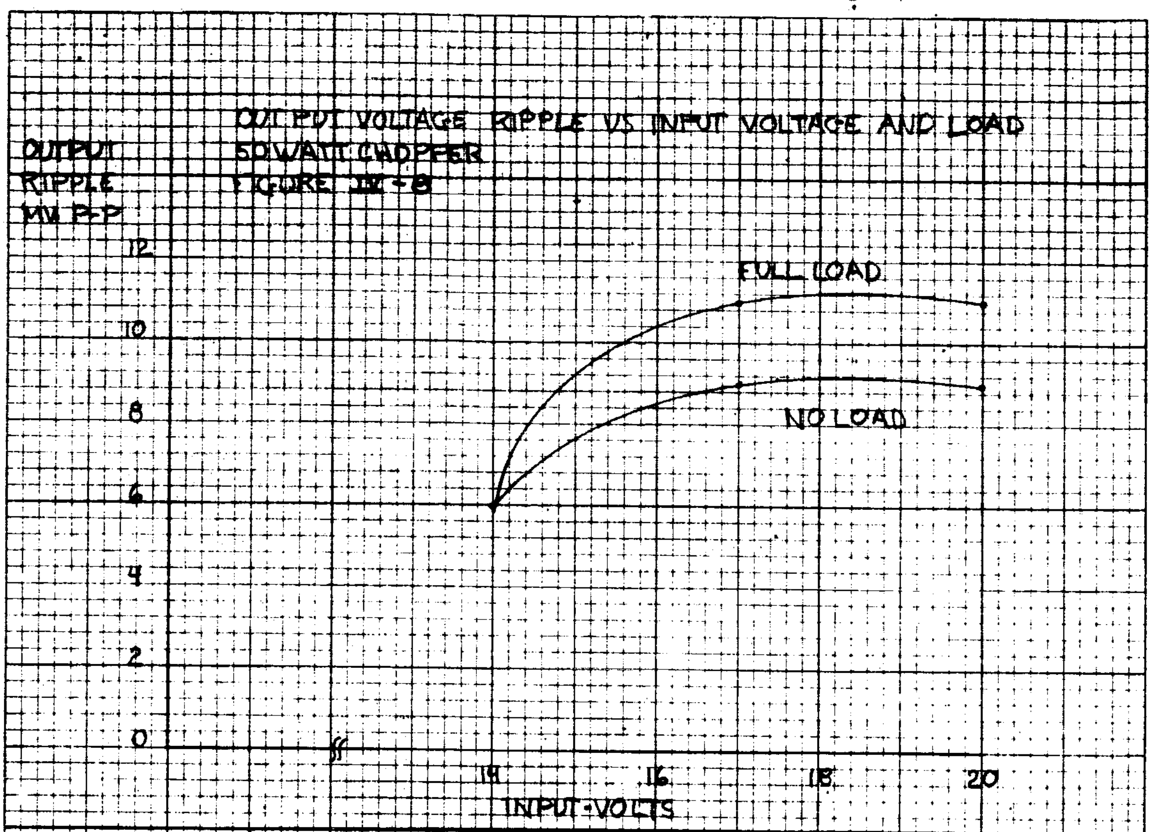

INPUT RIPPLE CURRENT VS INPUT VOLTAGE AND LOAD
25WATT CHOPPER
FIGURE IV-3
RIPPLE CURRENT MA. P-P
600
500
400
300
200
100
0
NO LOAD
12
14
16
18
20
INPUT-VOLTS
RIPPLE CURRENT
MA. P-P
2800
2400
2000
1600
1200
800
400
FULL LOAD
12
14
16
18
20
INPUT VOLTS


INPUT RIPPLE CURRENT VS INPUT VOLTAGE AND LOAD
50 WATT CHOPPER
FIGURE IV-4
RIPPLE CURRENT
MA. P-P
600
500
400
300
200
100
0
NO LOAD
14
16
18
20
INPUT-VOLTS
RIPPLE CURRENT
MA. P-P
4000
3500
3000
2500
2000
1500
1000
500
0
FULL LOAD
14
16
18
20
INPUT-VOLTS

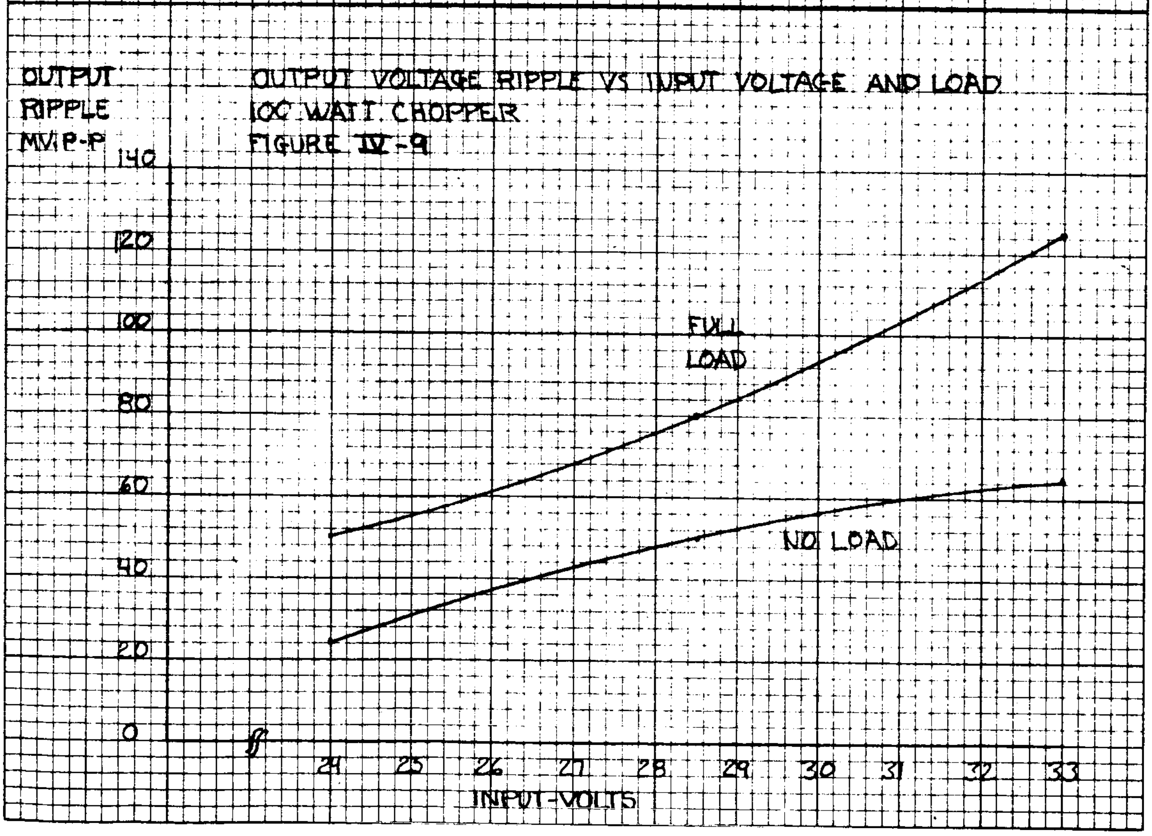

INPUT RIPPLE CURRENT VS INPUT VOLTAGE AND LOAD
100 WATT CHOPPER
FIGURE IV-5
RIPPLE CURRENT MA.P-P
700
600
500
400
300
200
100
0
NO LOAD
24 25 26 27 28 29 30 31 32 33
INPUT-VOLTS
RIPPLE CURRENT MA. P-P
7000
6000
5000
4000
3000
2000
1000
0
FULL LOAD
24 25 26 27 28 29 30 31 32 33
INPUT-VOLTS


OUTPUT VOLTAGE RIPPLE VS INPUT VOLTAGE AND LOAD
10 WATT CHOPPER
FIGURE IV-6
OUTPUT
RIPPLE
MV. P-P
12
10
8
6
4
2
0
12
14
16
18
20
INPUT-VOLTS
FULL LOAD
NO LOAD

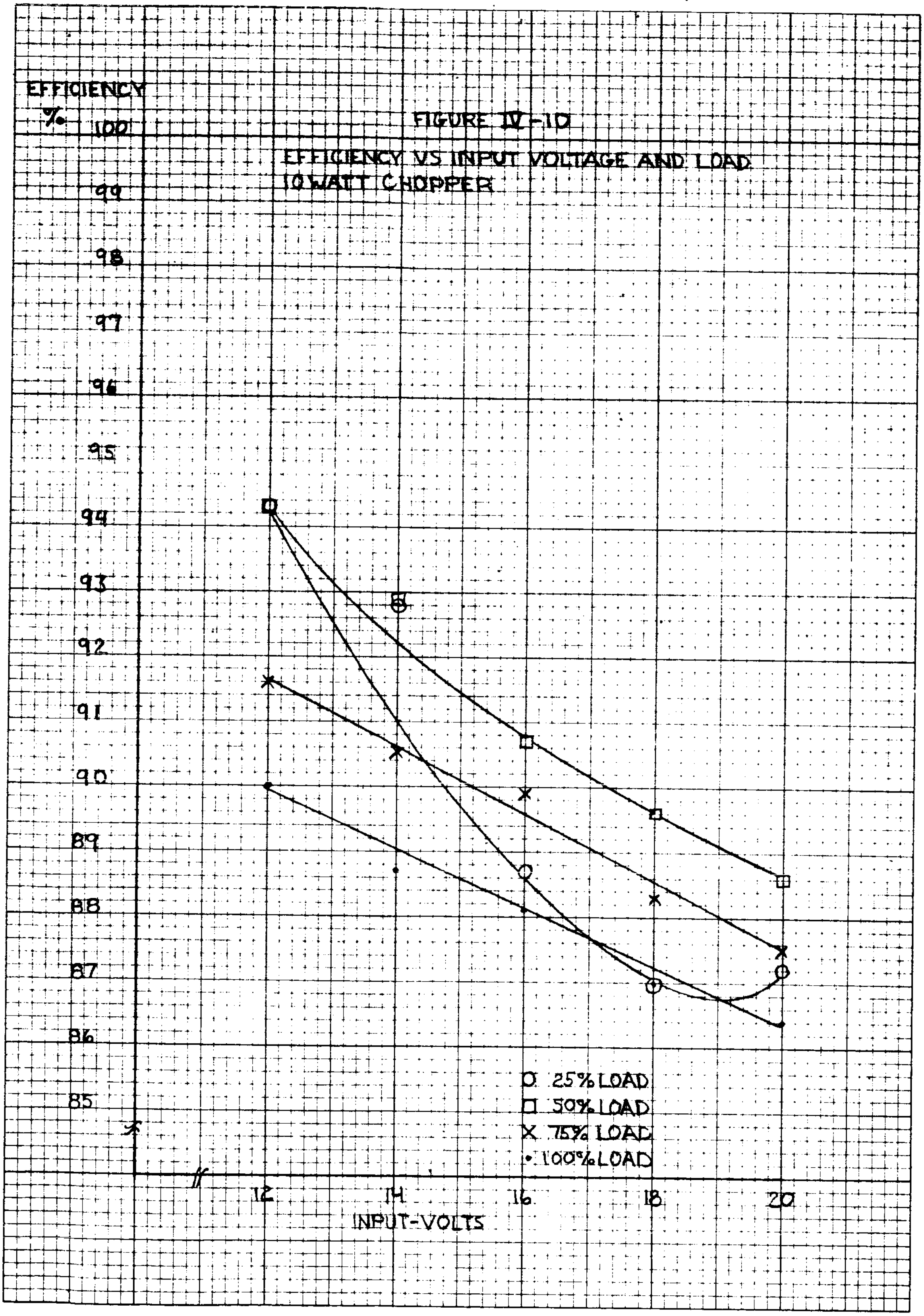

OUTPUT VOLTAGE RIPPLE VS. INPUT VOLTAGE, LOAD
25 WATT CHOPPER
FIGURE IV-7
OUTPUT
RIPPLE
MV. P-P
16
14
12
10
8
6
4
2
0
12
14
16
18
20
INPUT-VOLTS
FULL LOAD
NO LOAD

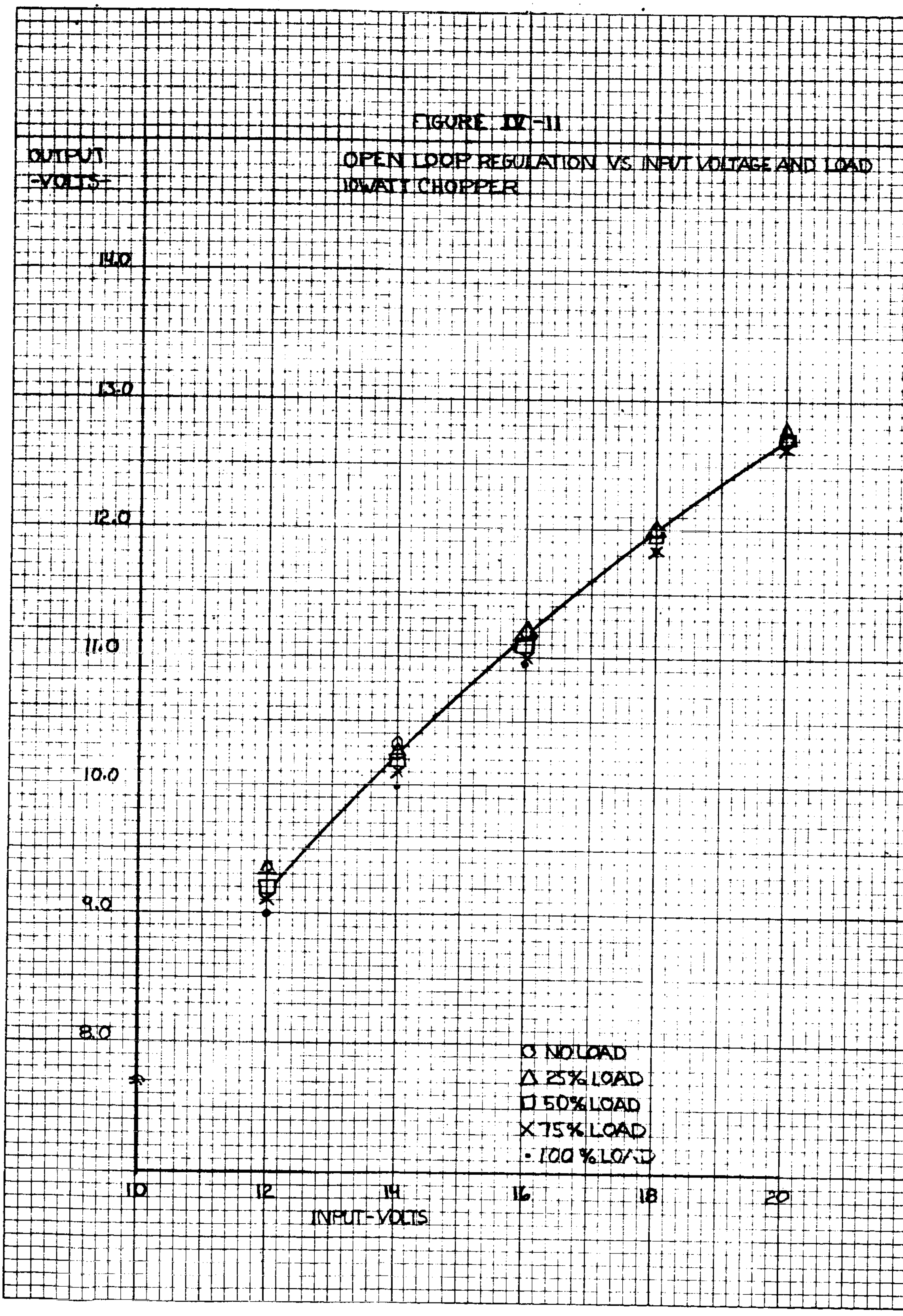


OUTPUT VOLTAGE RIPPLE VS INPUT VOLTAGE AND LOAD
50 WATT CHOPPER
FIGURE IV-8



OUTPUT VOLTAGE RIPPLE VS INPUT VOLTAGE AND LOAD
100 WATT CHOPPER
FIGURE IV-9


EFFICIENCY
%
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
FIGURE IV-10
EFFICIENCY VS INPUT VOLTAGE AND LOAD
10 WATT CHOPPER
O 25% LOAD
□ 50% LOAD
X 75% LOAD
• 100% LOAD
12
14
16
18
20
INPUT-VOLTS



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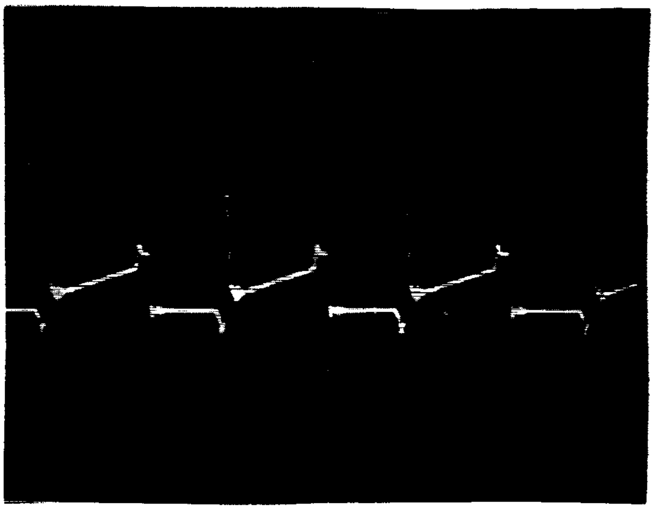
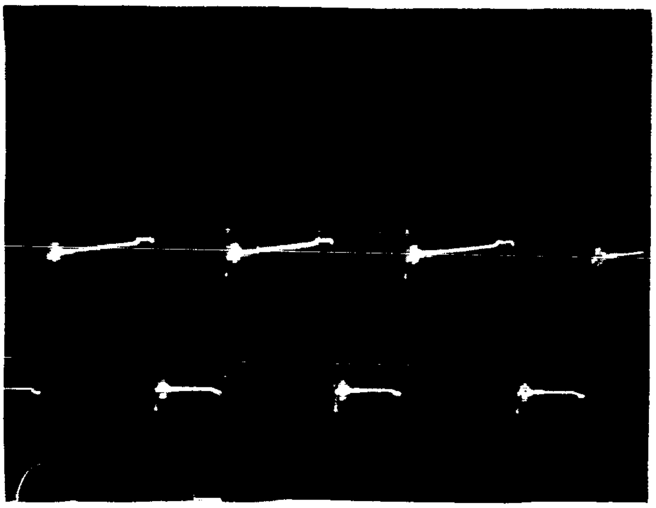
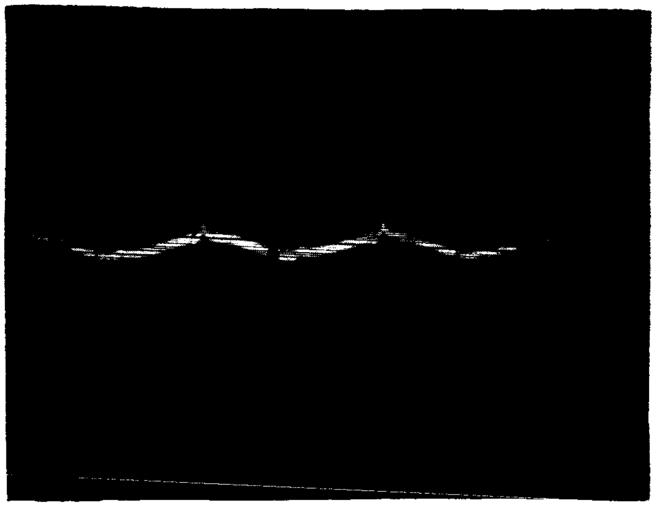


Input Ripple Current No Load 16 Volt Input
Vert. Scale: 95 ma/Div
Horz. Scale: 10 μsec/Div

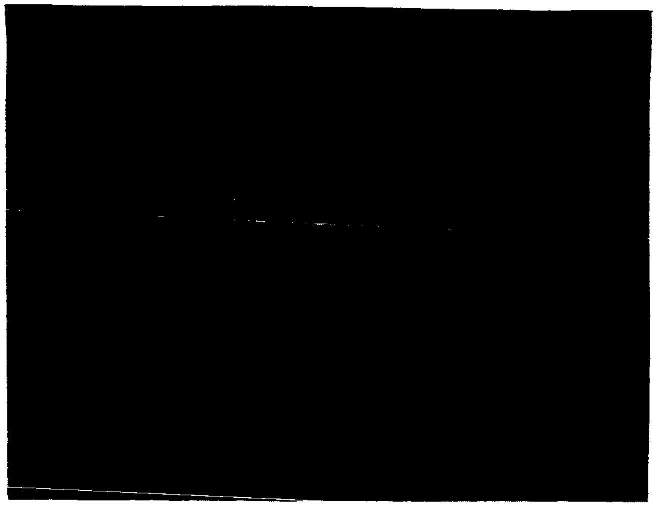


Input Ripple Current Full Load 16 Volt Input
Vert. Scale: 475 ma/Div
Horz. Scale: 10 μsec/Div

Figure IV-12 Input Ripple Current 10 Watt Chopper



Output Ripple Voltage No Load 16 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div



Output Ripple Voltage Full Load 16 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

Figure IV-13 Output Ripple Voltage 10 Watt Chopper

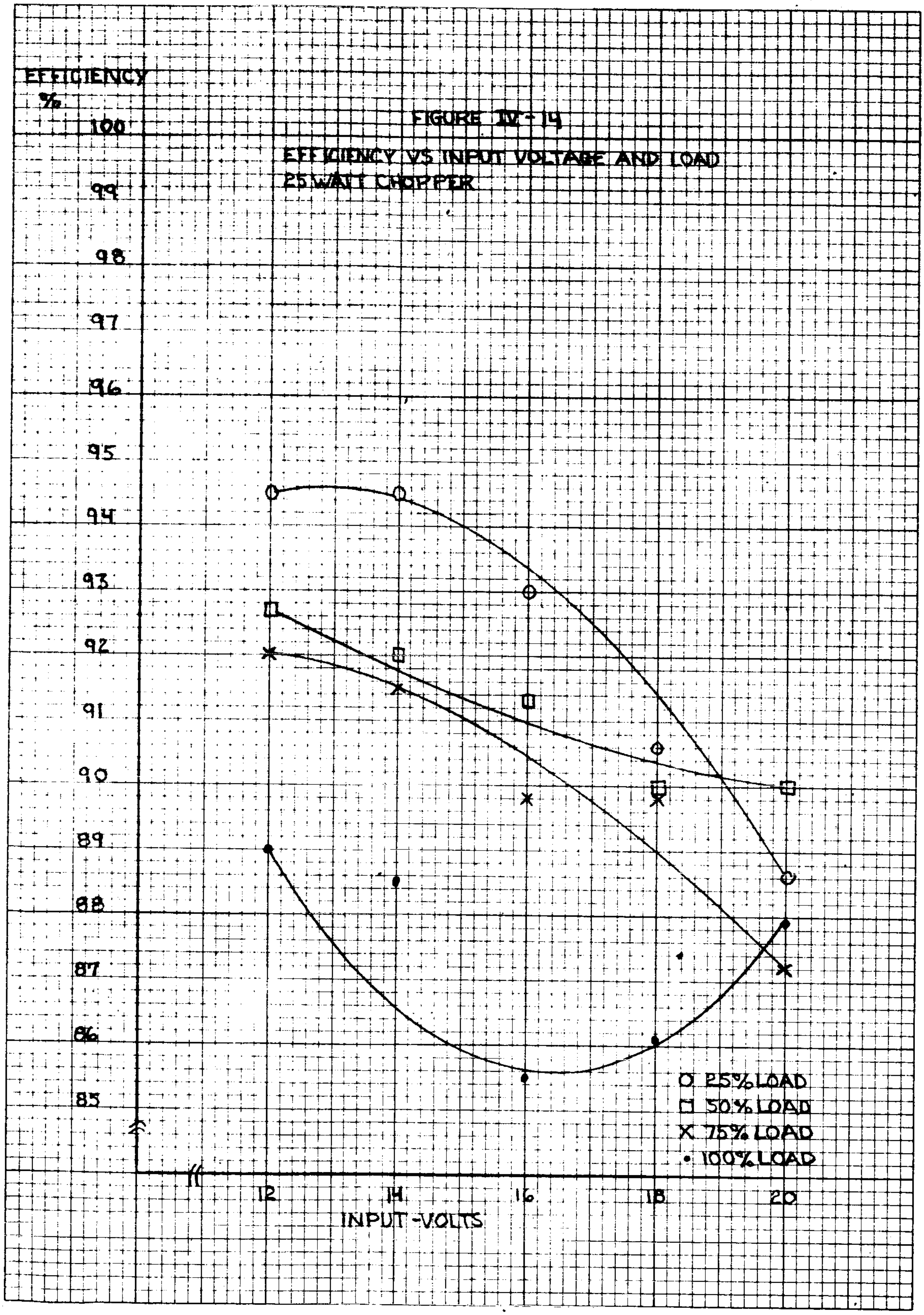
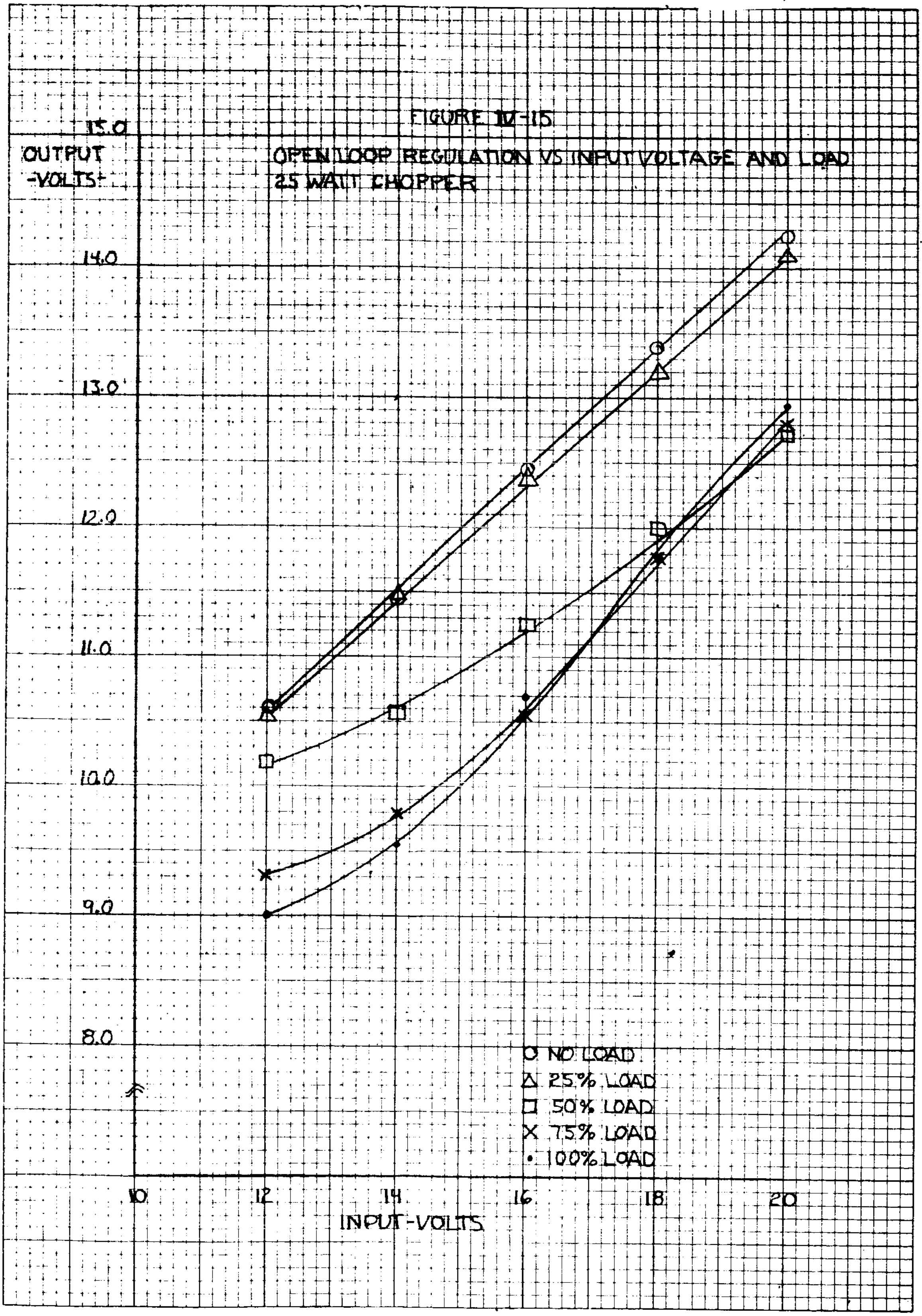


FIGURE IV-14
EFFICIENCY VS INPUT VOLTAGE AND LOAD
25 WATT CHOPPER



NO. 340R-10 DIETZGEN GRAPH PAPER 10 X 10 PER INCH
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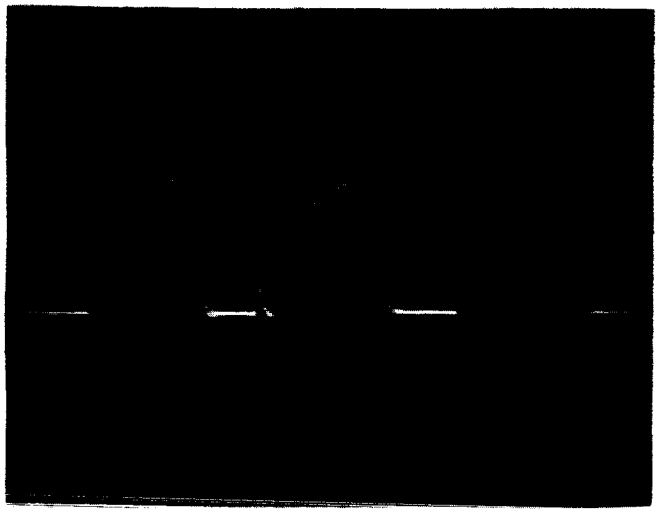
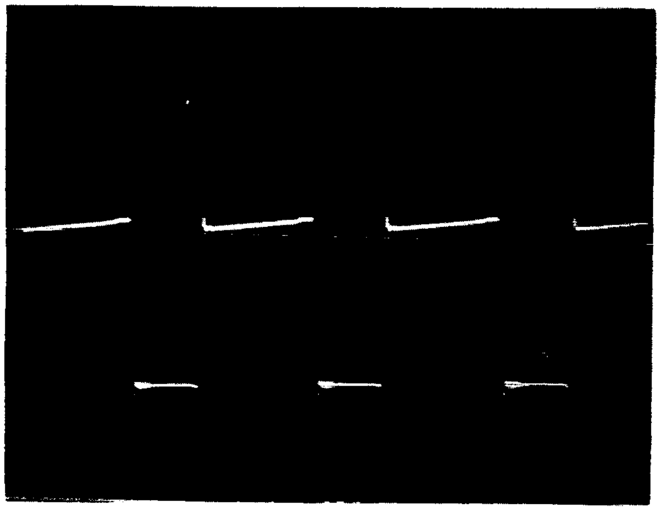
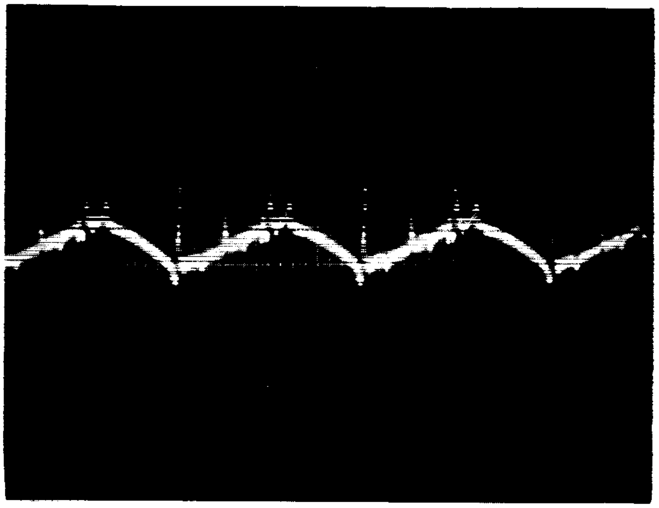


Input Ripple Current No Load 16 Volt Input
Vert. Scale 95 ma/Div
Horz. Scale: 10 μsec/Div

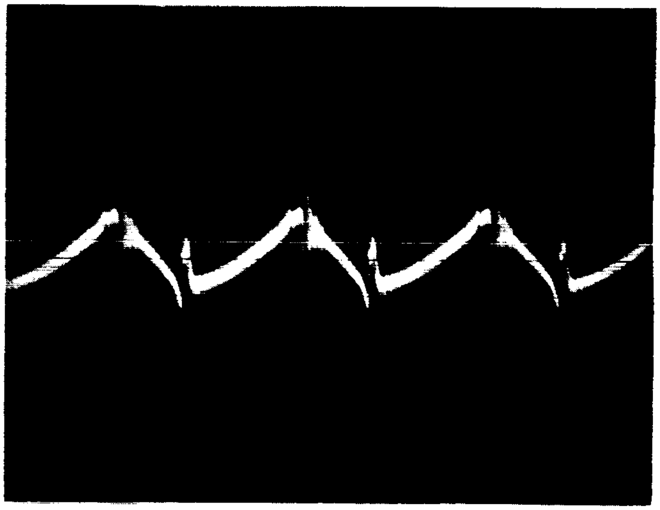


Input Ripple Current Full Load 16 Volt Input
Vert. Scale: 950 ma/Div
Horz. Scale: 10 μsec/Div

Figure IV-16 Input Ripple Current 25 Watt Chopper

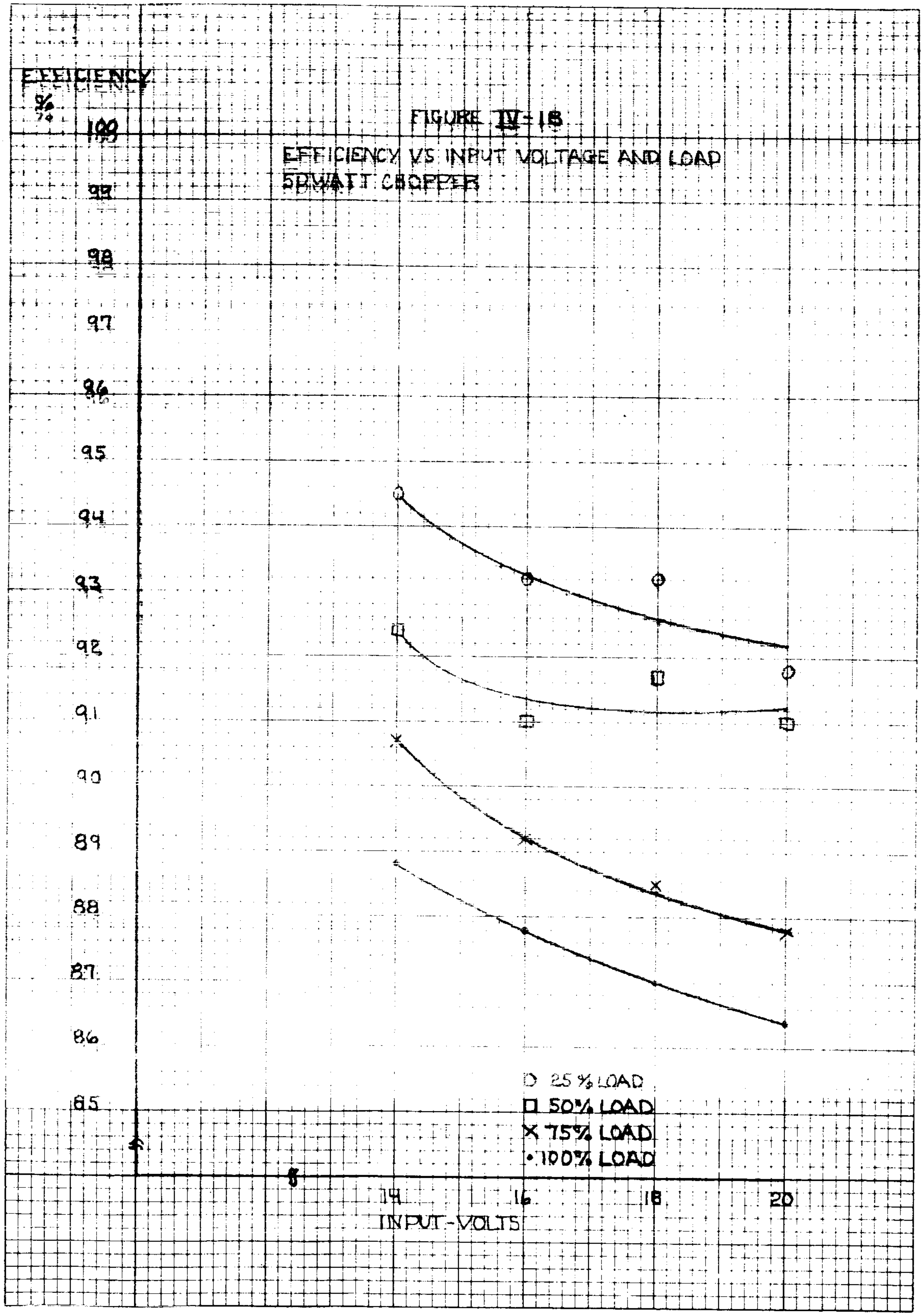


Output Ripple Voltage No Load 16 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div



Output Ripple Voltage Full Load 16 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

Figure IV-17 Output Ripple Voltage 25 Watt Chopper


EFFICIENCY
%
FIGURE IV-18
EFFICIENCY VS INPUT VOLTAGE AND LOAD
50 WATT CHOPPER
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
25% LOAD
50% LOAD
75% LOAD
100% LOAD
14
16
18
20
INPUT-VOLTS

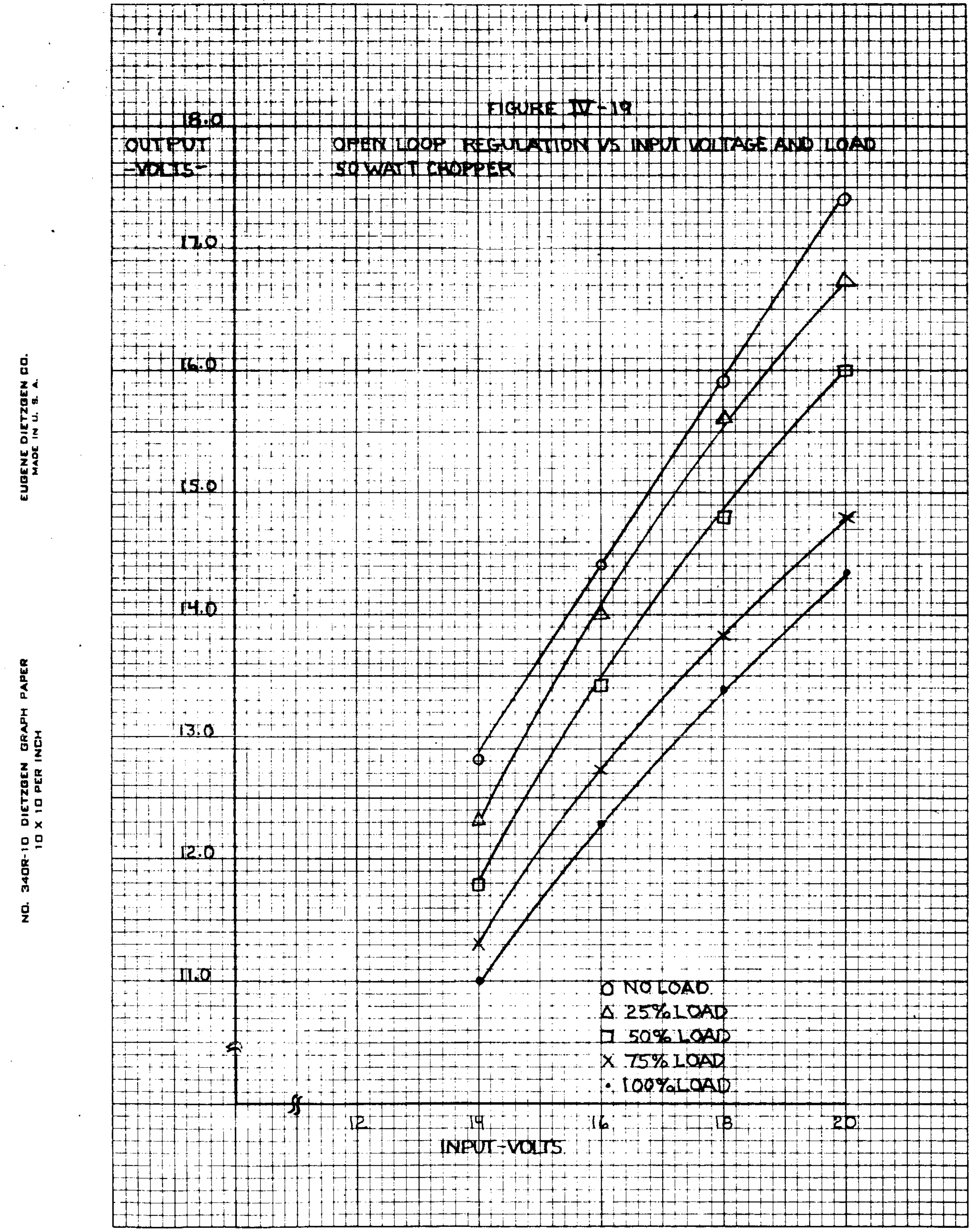


FIGURE IV-19
OPEN LOOP REGULATION VS INPUT VOLTAGE AND LOAD
50 WATT CHOPPER
OUTPUT
-VOLTS-
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
12
14
16
18
20
INPUT-VOLTS
O NO LOAD
Δ 25% LOAD
□ 50% LOAD
X 75% LOAD
• 100% LOAD
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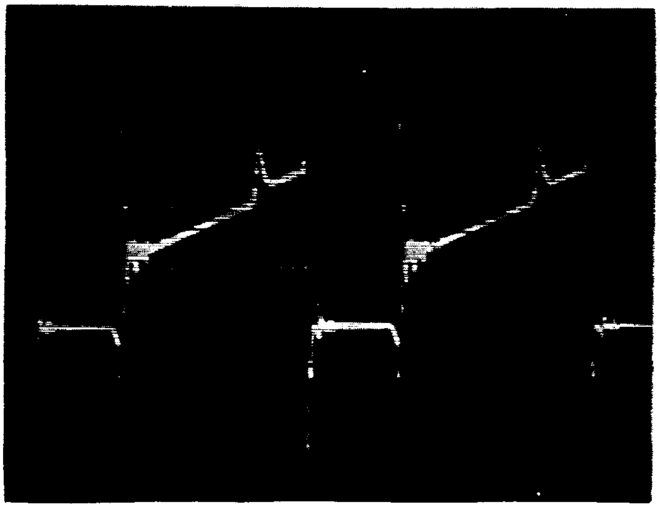
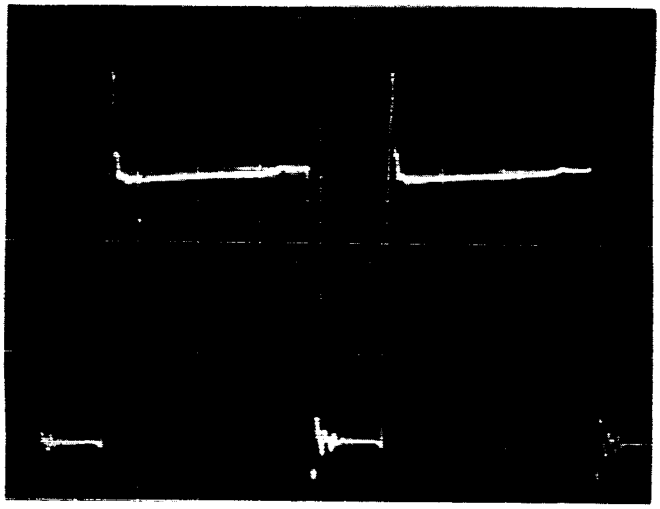
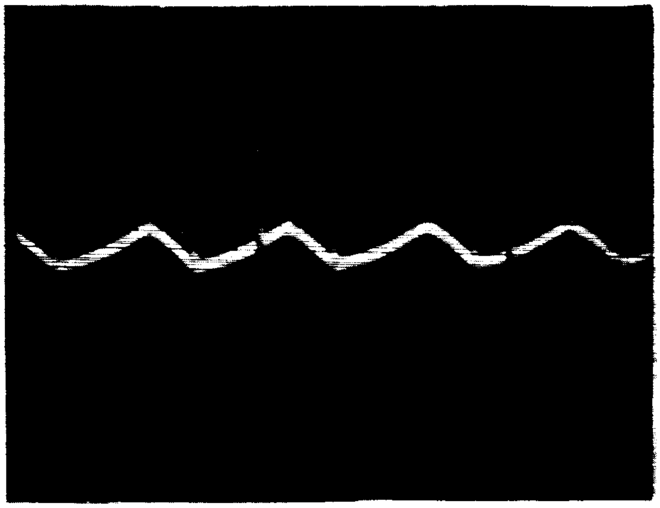


Input Ripple Current No Load 17 Volt Input
Vert Scale: 95 ma/Div
Horz. Scale: 10 μsec/Div

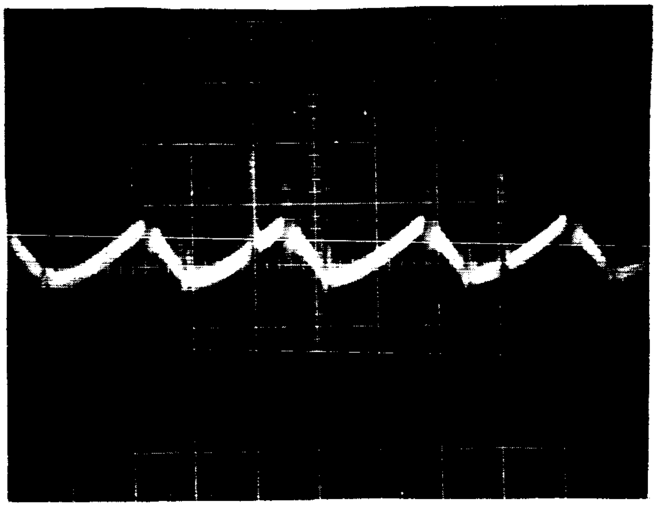


Input Ripple Current Full Load 17 Volt Input
Vert Scale: 950 ma/Div
Horz. Scale: 10 μsec/Div

Figure IV-20 Input Ripple Current 50 Watt Chopper

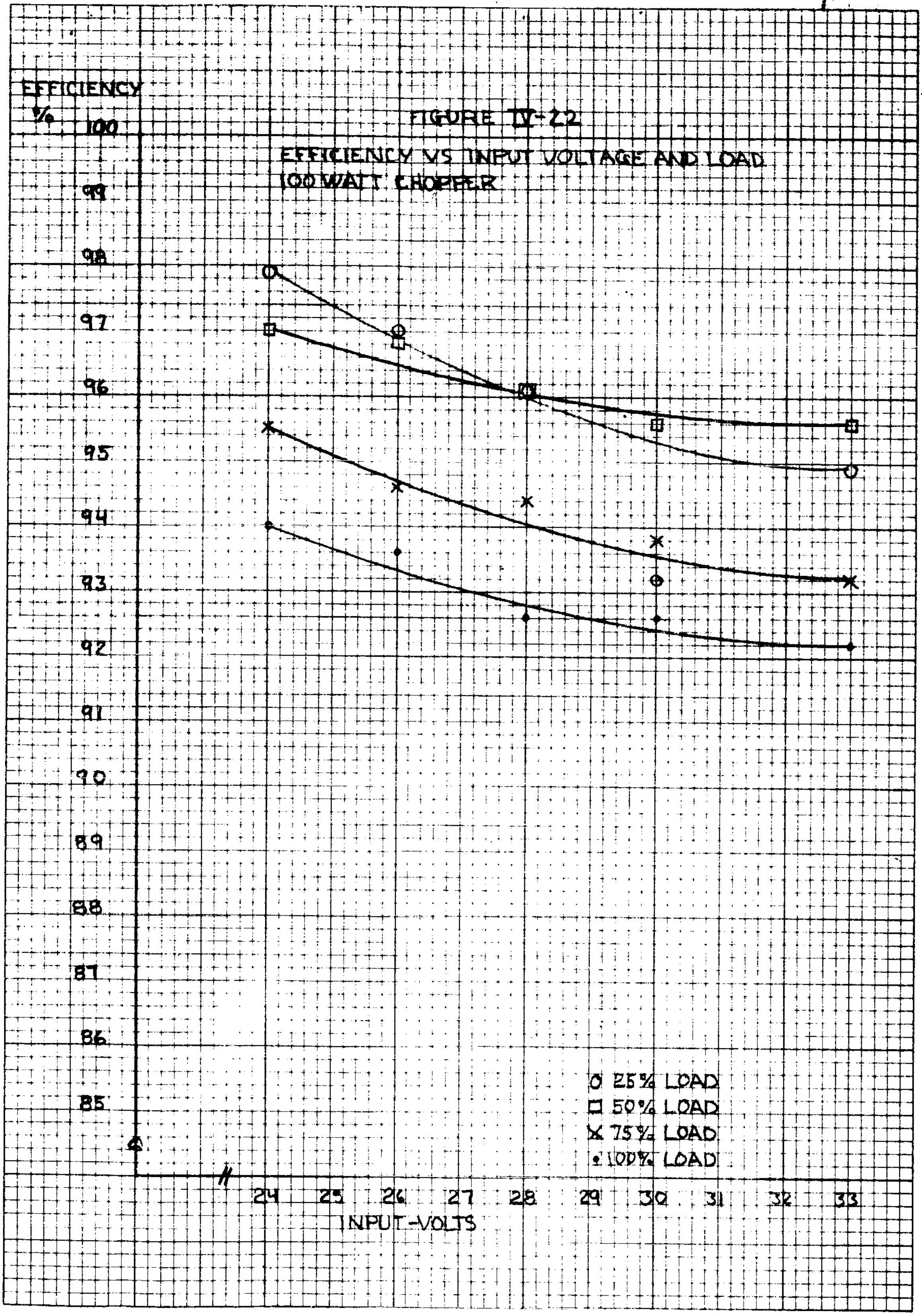


Output Ripple Voltage No Load 17 Volt Input
Vert. Scale: 10 mv/sec
Horz. Scale: 10 μsec/Div



Output Voltage Ripple Full Load 17 Volt Input
Vert. Scale: 10 mv/Div
Horz. Scale: 10 μsec/Div

Figure IV-21 Output Voltage Ripple 50 Watt Chopper


EFFICIENCY
%
FIGURE IV-22
EFFICIENCY VS INPUT VOLTAGE AND LOAD
100 WATT CHOPPER
100
99
98
97
96
95
94
93
92
91
90
89
88
87
86
85
0
24
25
26
27
28
29
30
31
32
33
INPUT-VOLTS
O 25% LOAD
□ 50% LOAD
X 75% LOAD
• 100% LOAD

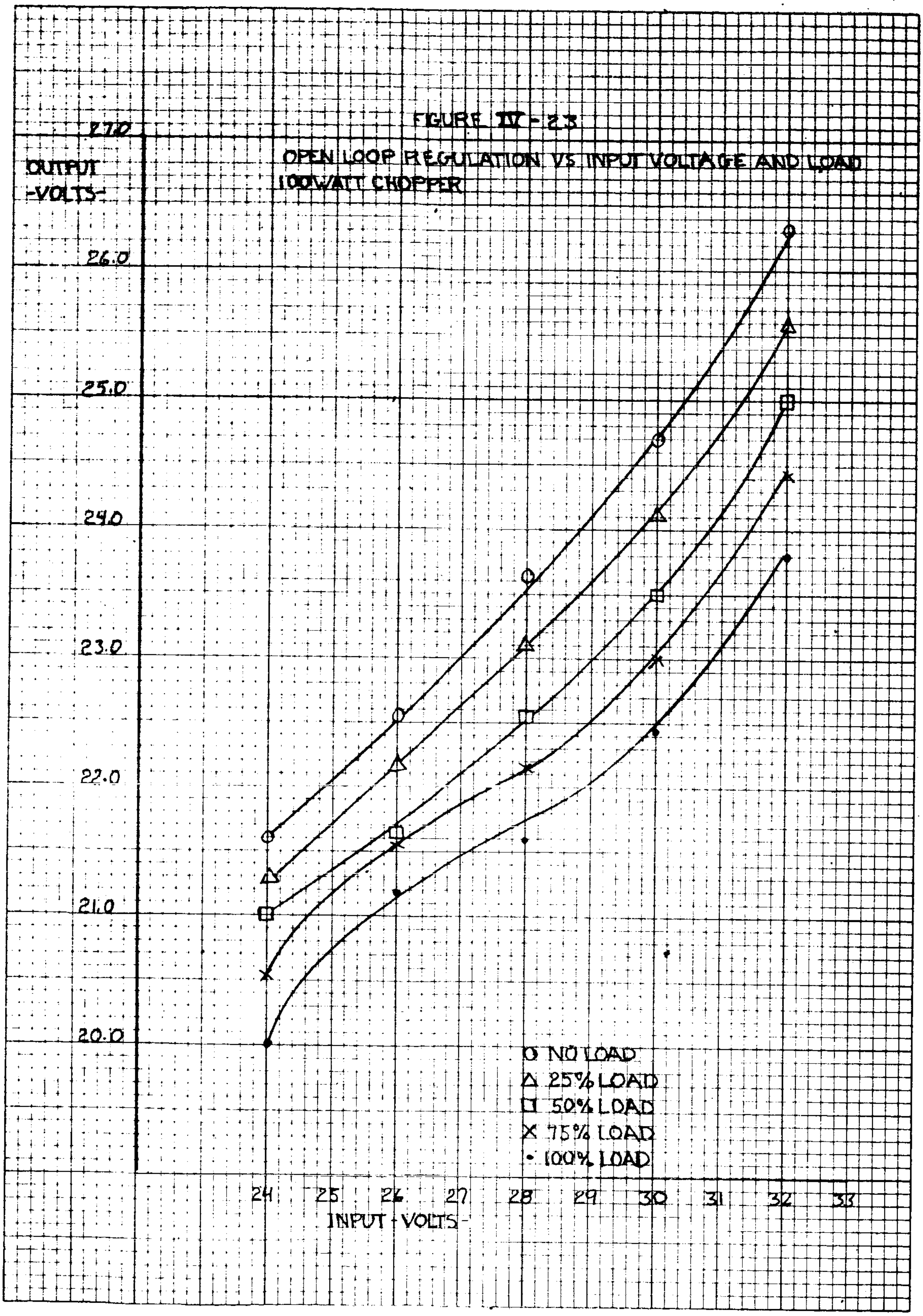
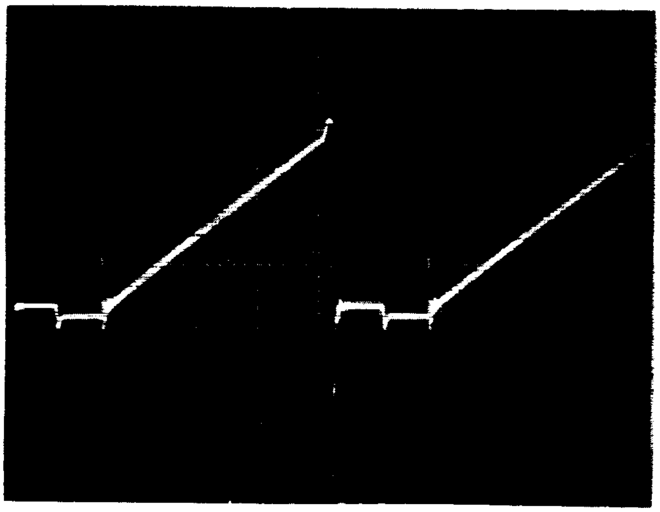
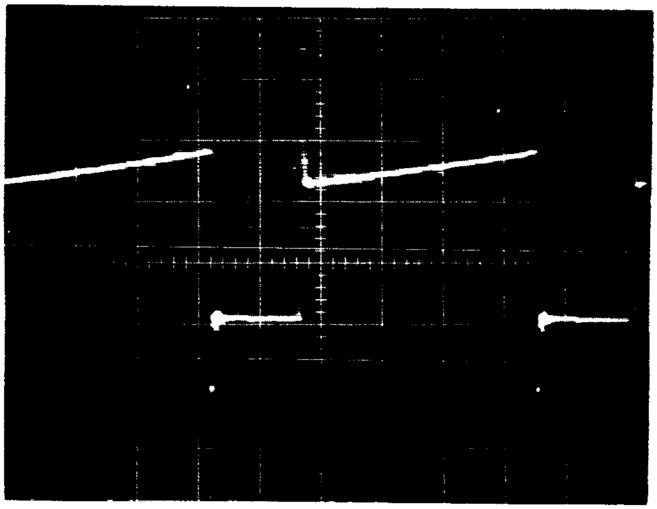


FIGURE IV - 23
OPEN LOOP REGULATION VS INPUT VOLTAGE AND LOAD
100 WATT CHOPPER
OUTPUT -VOLTS-
27.0
26.0
25.0
24.0
23.0
22.0
21.0
20.0
O NO LOAD
Δ 25% LOAD
□ 50% LOAD
X 75% LOAD
• 100% LOAD
24
25
26
27
28
29
30
31
32
33
INPUT - VOLTS -

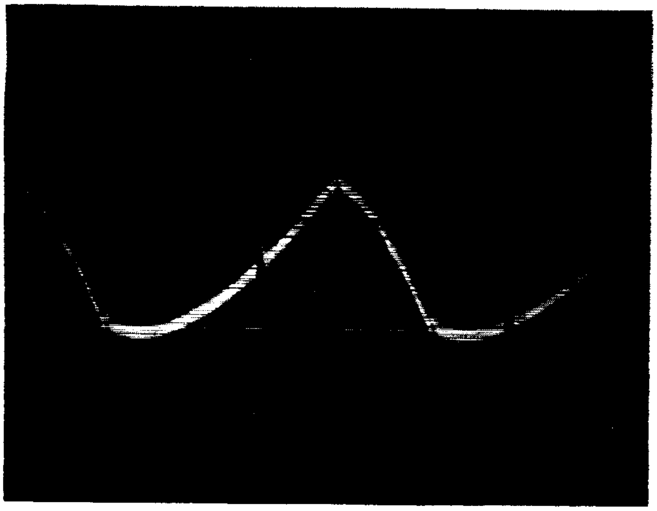


Input Current Ripple No Load 28.5 Volt Input
Vert. Scale: 190 ma/Div
Horz. Scale: 10 μsec/Div

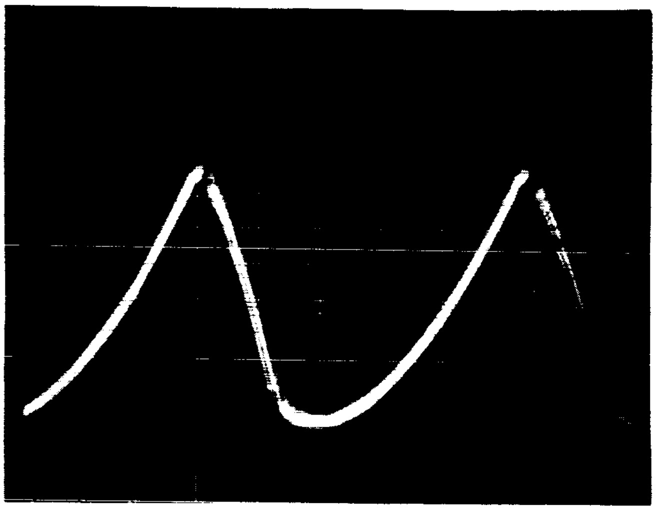


Input Current Ripple Full Load 28.5 Volt Input
Vert Scale: 1.9A/Div
Horz Scale: 10 μsec/Div

Figure IV-24 Input Current Ripple 100 Watt Chopper



Output Ripple Voltage No Load 28.500 Volt Input
Vert. Scale: 20 mv/Div
Horz. Scale: 10 μsec/Div



Output Ripple Voltage Full Load 28.5 Volt Input
Vert. Scale: 20 mv/Div
Horz. Scale: 10 μsec/Div

Figure IV-25 Output Ripple Voltage 100 Watt Chopper

APPENDIX V

Component Size and Weight Summary
Booster Regulator Converters

SIZE AND WEIGHT ANALYSIS

A size and weight analysis was made on the booster series of power supplies. For the analysis, each booster was broken down into the following circuit functions:

1. Oscillator

2. Voltage Regulator

3. Sawtooth Former

4. Pulse Width Modulator/Driver

5. B+ Supply

6. Power Stage/Input Filter/Output Filter

7. Overload Protection

8. Short Circuit Protection

The weight and the volume of all electrical components of each circuit function were determined using the following assumptions:

1. Resistors, tubular capacitors, diodes and transistors except stud mounted types were taken as geometric cylinders excluding leads. Stud mounted components were taken as geometric cylinders including mounting hardware and leads.

2. Mica capacitors were taken as rectangular solids excluding leads.

3. All magnetics were torroids and were taken as geometric cylinders excluding leads.

Table V-I and V-II summarize the size and weight analysis for the 10, 25, 50 and 100 watt boosters. The curve in Figure V-I show how the electrical component volume and weight of the boosters compare with the design goals.

Table V-I Electrical Component Weight (Lbs.)

	10W	25W	50W	100W
Oscillator	.0075	.0075	.0075	.0075
Voltage Regulator	.0248	.0248	.0248	.0248
Sawtooth Former	.0064	.0064	.0064	.0064
Pulse Width Modulator/Driver*	.0481	.0481	.0481	.0481
B+ Supply	.0057	.0057	.0057	.0107
Power Stage/Input Filter/Output Filter	.1757	.2704	.4933	.4407
Overload Protection	.0668	.0668	–	–
Short Circuit Protection	–	–	.0553	.0553
Total (Lbs.)	.3350	.4297	.6411	.5938

Table V-II Electrical Component Volume (cu. in.)

	10W	25W	50W	100W
Oscillator	.0790	.0790	.0790	.0790
Voltage Regulator	.3192	.3192	.3192	.3192
Sawtooth Former	.0623	.0623	.0623	.0623
Pulse Width Modulator/Driver	.4432	.4432	.4432	.4293
B+ Supply	.0480	.0480	.0480	.0856
Power Stage/Input Filter/Output Filter	1.2744	2.3724	4.5590	4.3410
Overload Protection	.9256	.9256	–	–
Short Circuit Protection	–	–	.7673	.7673
Total (cu. in.)	3.1517	4.2497	6.2780	6.0837

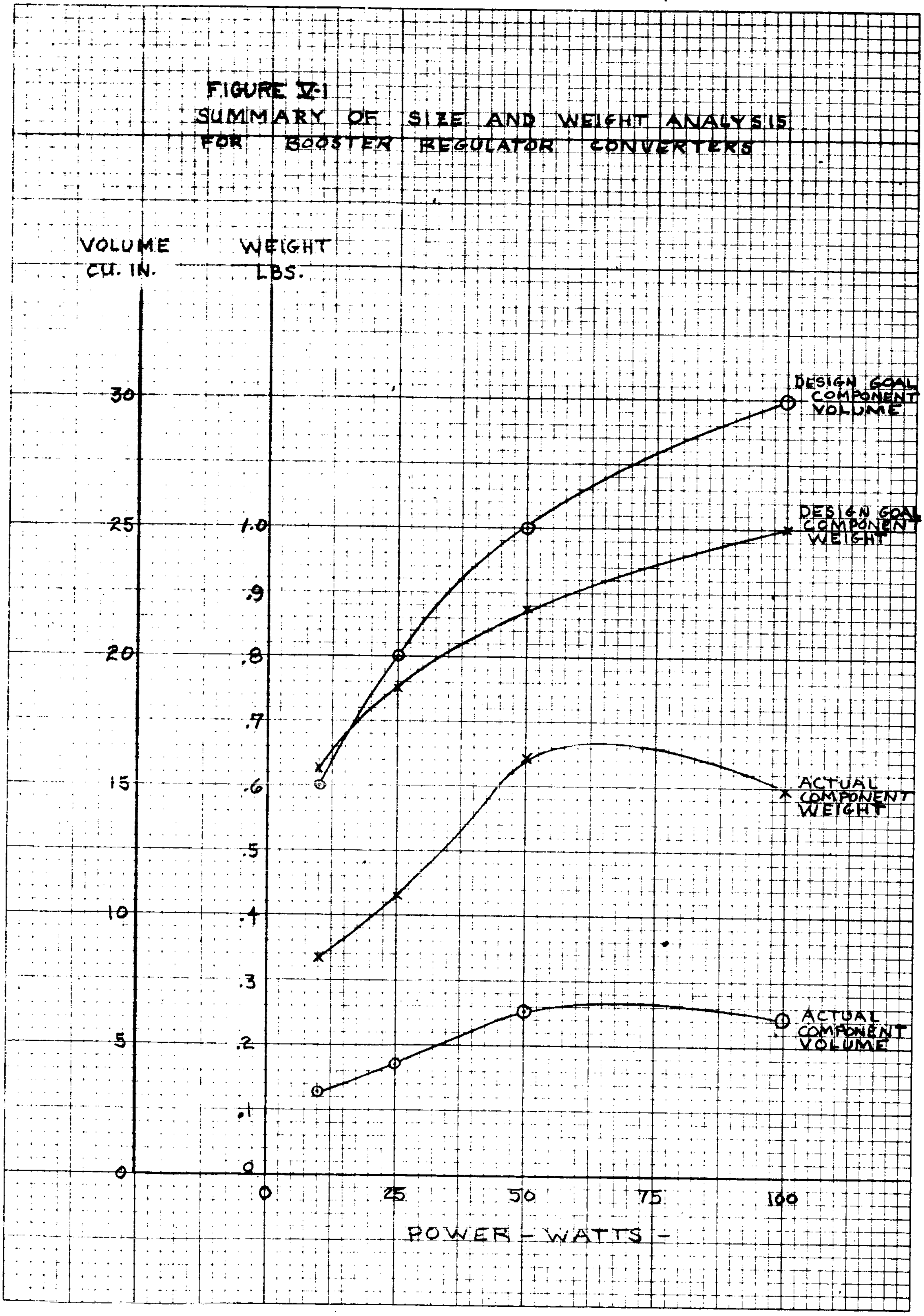


FIGURE V-1
SUMMARY OF SIZE AND WEIGHT ANALYSIS
FOR BOOSTER REGULATOR CONVERTERS
VOLUME CU. IN.
WEIGHT LBS.
30
25
20
15
10
5
0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
25
50
75
100
POWER - WATTS -
DESIGN GOAL COMPONENT VOLUME
DESIGN GOAL COMPONENT WEIGHT
ACTUAL COMPONENT WEIGHT
ACTUAL COMPONENT VOLUME

APPENDIX VI

Modularization Program

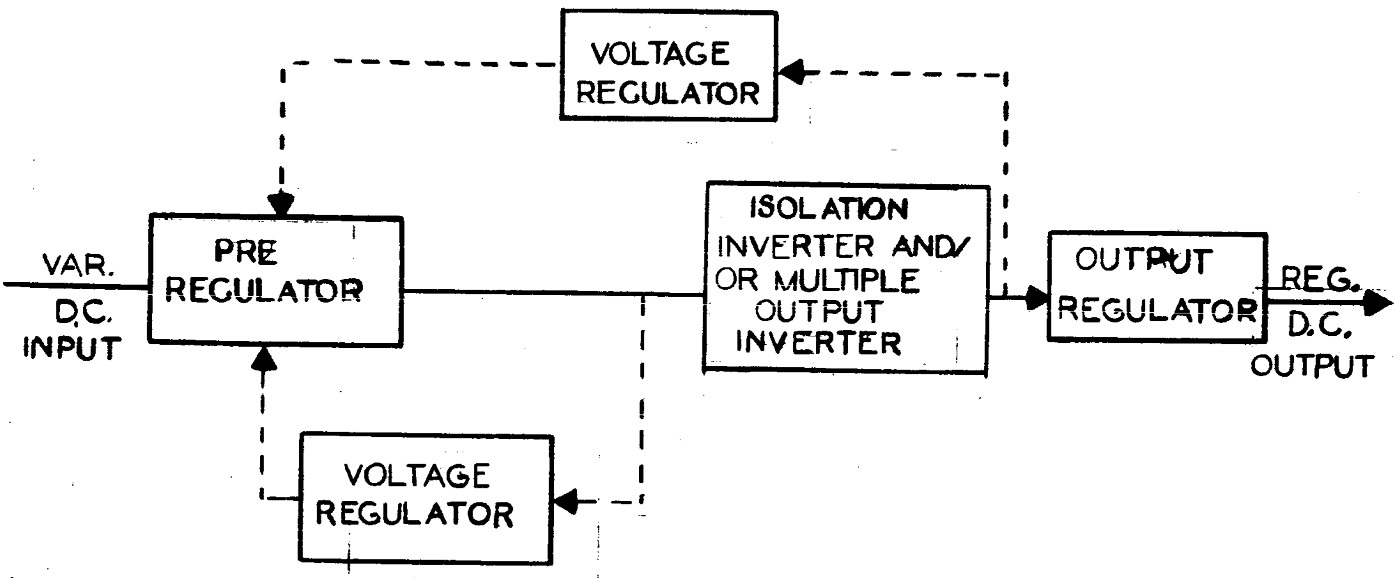
For

Satellite Power Conditioning Systems

MODULARIZATION PROGRAM FOR SATELLITE POWER CONDITIONING SYSTEMS

I. Objective of Overall Program - To satisfy satellite power conversion system requirements by utilization of modularization concepts for the power conversion circuits. To be accomplished by developing basic building block circuits applying state-of-the-art techniques to obtain maximum efficiency and minimum size and weight consistent with present and anticipated scientific satellite load and power source characteristics. To obtain flexible utilization of these basic building block circuits to satisfy a large range of anticipated satellite power conditioning system requirements.

II. Anticipated Modular Breakdown



Block Functions

A. Pre-regulator. This block has capability as a pre-regulator in the above block diagram providing regulation against input line variations. This block also has the capability of being operated as a booster or chopper type power supply providing regulation against line and load variations.

B. Isolation Inverter. The isolation inverter provides the following functions:

Isolation

Voltage Transformation

Single or Multiple Outputs

C. Output Regulator. The output regulator provides the matching characteristics to the load such as:

Ripple Voltage Filtering

Voltage Regulation

Transient Recovery

Dynamic Voltage Regulation

Output Impedance

III. Present Program NAS 5-3921 - The present program is an initial step in this modularization concept and is limited in scope to the pre-regulator circuit. Specific effort is being directed toward research, design and development of power circuits, control circuits, and filter circuits required to perform the pre-regulator function.

Two basic circuits are being developed. The chopper series of power supplies are maintaining a regulated output voltage slightly below the minimum input line. The booster series of power supplies are maintaining a regulated output voltage slightly above the maximum input line.

High frequency switching is being investigated for size and weight considerations. Maximum switching frequency is being balanced against over all conversion efficiency.

Self-stabilizing techniques are being investigated for the dynamic regulation requirements. These techniques are to provide automatic compensation against input line variations. Input current ripple limits as well as output voltage ripple limits are being satisfied.

Power supplies are being designed for 4 basic output power levels. 10 watts, 25 watts, 50 watts and 100 watts.

The end result of the present program will be complete closed loop controlled breadboarded power supplies in the above power levels. These power supplies will have specified characteristics in voltage regulation, input current and output voltage ripple, dynamic regulation, recovery time, efficiency, and circuit protection.

IV. Future Program Effort - Two possible programs of follow-on effort could be considered.

A. Packaging of Pre-regulator circuit.

A packaging program could be initiated toward either conventional packaging or microminiaturization taking into consideration the following environmental requirements.

1. Temperature
2. Pressure
3. Humidity
4. Vibration - sinusoidal and random excitation
5. Magnetic field characteristics
6. Electromagnetic Interference Suppression

Special packaging considerations will be required for high frequency switching techniques being developed in the present NASA program. If a microminiaturization program is to be considered, additional circuit work will be required to adapt and modify the present circuits to practical microcircuit techniques.

B. Continuation of Modularization Program Future program effort could be directed toward completion of a breadboard modular system similar to that previously discussed. Specific items to be covered would include:

1. Investigation of high efficiency, high switching frequency circuits for the basic isolation inverter circuits.

2. Investigation of highly efficient output regulator circuits having the characteristics of the regulators discussed above.

3. Means of obtaining multiple outputs from the isolation inverter block.

4. Interface requirements of the modular building blocks.

5. Transient response characteristics and stability of complete modular system.

6. Circuit protection methods for each of the possible modular systems.

APPENDIX VII

DRAWINGS, PARTS LISTS

PHASE I

BOOSTERS

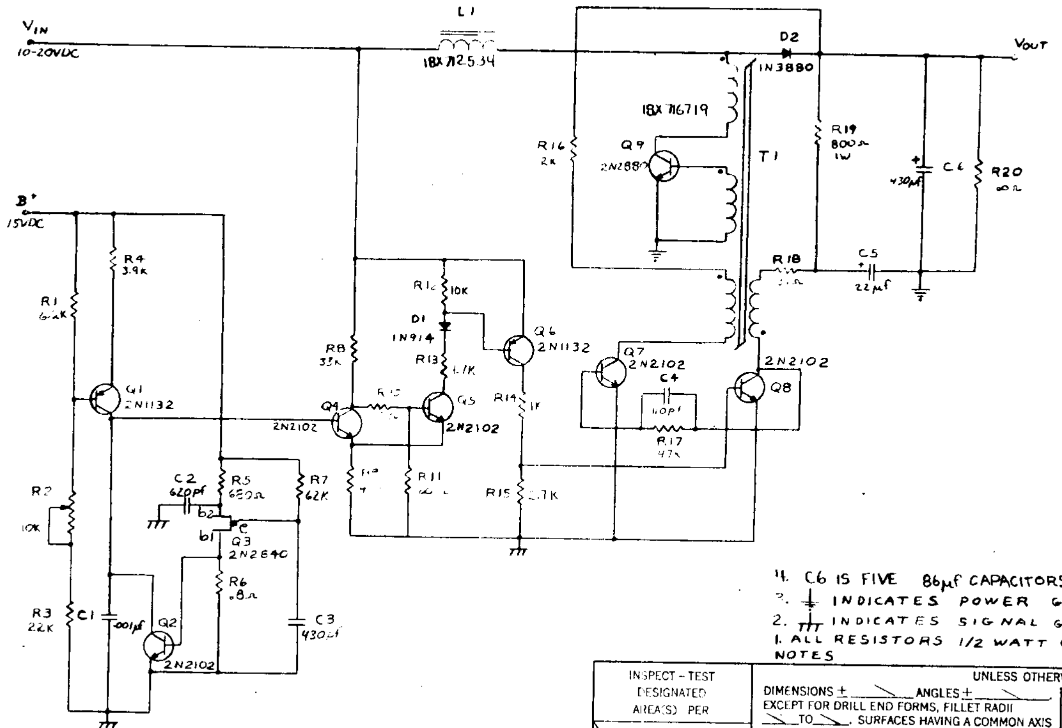
HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 10 WATT
PARTS LIST NO. SK63246

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6
5	2N2102	R.C.A.	TRANSISTOR, Q2, Q4, Q5, Q7, Q8
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q3
1	2N2880	SOLITRON	TRANSISTOR, POWER, Q9
1	1N914	TRANSITRON	DIODE, D1
1	1N3880	WESTINGHOUSE	DIODE, D2
1	.001 µf	C.D. 22A5D1	CAPACITOR, C1
1	620 pf	C.D. 5A5T62JE	CAPACITOR, C2
1	430 pf	C.D. 22A5T43JE	CAPACITOR, C3
1	110 pf	C.D. 22A5T11JE	CAPACITOR, C4
1	22 µf	TANSITOR TEF 20-50C31	CAPACITOR, C5
5	56 µf	G.E. 69F4856	CAPACITOR, C6
1	10 K	A-B MIL-R-11	RESISTOR, VARIABLE, R2
1	6.2 K	A-B MIL-R-11	RESISTOR, R1
1	22 K	A-B MIL-R-11	RESISTOR, R3
1	3.9 K	A-B MIL-R-11	RESISTOR, R4
1	680 Ω	A-B MIL-R-11	RESISTOR, R5
1	68 Ω	A-B MIL-R-11	RESISTOR, R6
1	62 K	A-B MIL-R-11	RESISTOR, R7
1	33 K	A-B MIL-R-11	RESISTOR, R8
2	4.7K	A-B MIL-R-11	RESISTOR, R9, R13
1	10 K	A-B MIL-R-11	RESISTOR, R12
1	1 K	A-B MIL-R-11	RESISTOR, R14
1	2.7 K	A-B MIL-R-11	RESISTOR, R15
1	2 K	A-B MIL-R-11	RESISTOR, R16
1	47 K	A-B MIL-R-11	RESISTOR, R17
1	36 Ω	A-B MIL-R-11	RESISTOR, R18
1	800 Ω	A-B MIL-R-11	RESISTOR, 1 WATT, R19
1	18X712534	HAMILTON STANDARD	CHOKE, L1
1	18X716719	HAMILTON STANDARD	TRANSFORMER, T1

SYM	DESCRIPTION	DATE	APPROV

REVISIONS



SK63246

4. C6 IS FIVE 86μf CAPACITORS IN PARALLEL
3. ⏚ INDICATES POWER GROUND
2. ⊥ INDICATES SIGNAL GROUND
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
NOTES

INSPECT - TEST DESIGNATED AREA(S) PER

DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___. SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR ___
△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550 C P

NEXT ASSY	USED ON
APPLICATION	

MATERIAL	
HARDNESS	
HEAT TREAT SPEC	
SURFACE COATING	
MFG SPEC	
MAKE FROM	
PROD. CODE	

DRAWN	Peter G. Barri	1/21/66
CHECKED	Richard F. Lane	1/21/66
DRAFTING		
DESIGN		
MATERIALS		
PROJECT	F. Rapson	1/25/66
COST		
FACTORY		

EXP MFG	PRELIM PROD	PROD
2-2-66		

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC
DC TO DC CONVERTER
BOOSTER 10 WATT

CODE IDENT NO.	SIZE	
73030	C	SK63246

SCALE: WEIGHT: LB SHEET

NASA STUDY PROGRAM

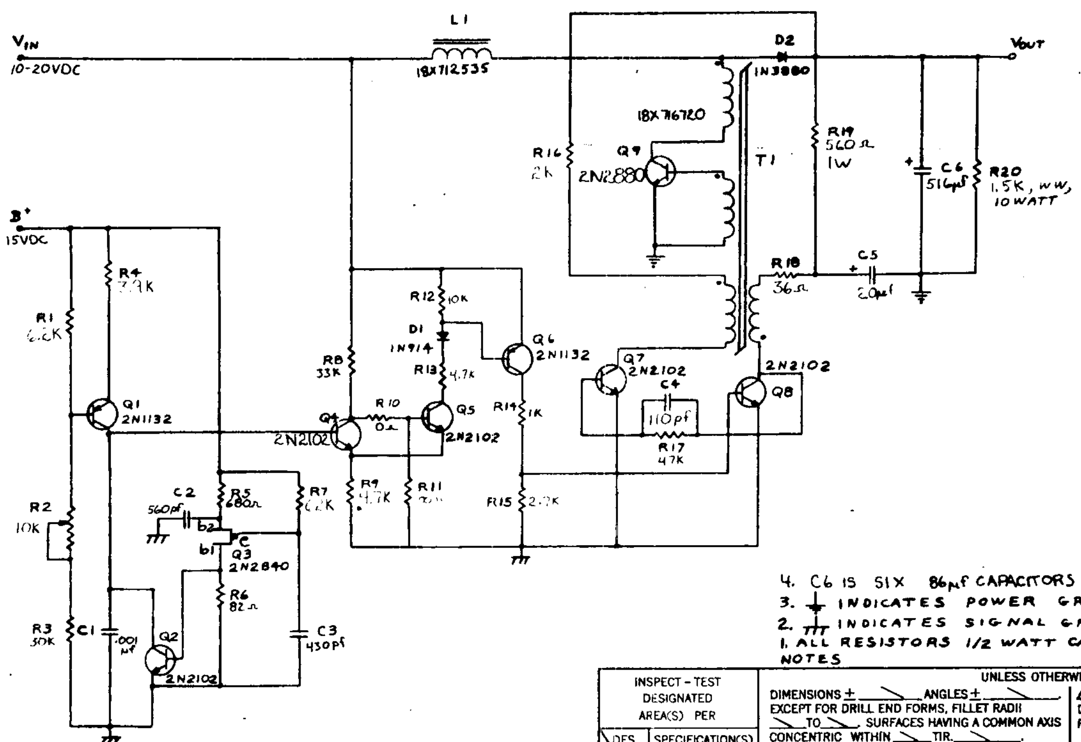
HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 25 WATT
PARTS LIST NO. SK63247

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6
5	2N2102	R.C.A.	TRANSISTOR, Q2, Q4, Q5, Q7, Q8
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q3
1	2N2880	SOLITRON	TRANSISTOR, POWER, Q9
1	1N914	TRANSITRON	DIODE, D1
1	1N3880	WESTINGHOUSE	DIODE, D2
1	.001 µf	C.D. 22A5D1	CAPACITOR, C1
1	560 pf	C.D. 22A3T56JE	CAPACITOR, C2
1	430 pf	C.D. 22A5T43 JE	CAPACITOR, C3
1	110 pf	C.D. 22A5T11 JE	CAPACITOR, C4
1	20 µf	TANSITOR W20-85D3K	CAPACITOR, C5
6	86 µf	G.E. 69F4856	CAPACITOR, C6
1	10 K	A-B MIL-R-11	RESISTOR, VARIABLE, R2
1	6.2 K	A-B MIL-R-11	RESISTOR, R1
1	30 K	A-B MIL-R-11	RESISTOR, R3
1	3.9 K	A-B MIL-R-11	RESISTOR, R4
1	680 Ω	A-B MIL-R-11	RESISTOR, R5
1	82 Ω	A-B MIL-R-11	RESISTOR, R6
1	62 K	A-B MIL-R-11	RESISTOR, R7
1	33 K	A-B MIL-R-11	RESISTOR, R8
2	4.7 K	A-B MIL-R-11	RESISTOR, R9, R13
1	10 K	A-B MIL-R-11	RESISTOR, R12
1	1 K	A-B MIL-R-11	RESISTOR, R14
1	2.7 K	A-B MIL-R-11	RESISTOR, R15
1	2 K	A-B MIL-R-11	RESISTOR, R16
1	47 K	A-B MIL-R-11	RESISTOR, R17
1	36 Ω	A-B MIL-R-11	RESISTOR, R18
1	560 Ω	A-B MIL-R-11	RESISTOR, 1 WATT, R19
1	1.5 K	CLAROSTAT	RESISTOR, WW, 10 WATT, R20
1	18X712535	HAMILTON STANDARD	CHOKE, L1
1	18X716720	HAMILTON STANDARD	TRANSFORMER, T1

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL

SK63247



4. C6 IS SIX 86μf CAPACITORS IN PARALLEL
3. ⏚ INDICATES POWER GROUND
2. ⫨ INDICATES SIGNAL GROUND
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
NOTES

INSPECT - TEST DESIGNATED AREA(S) PER

DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___, SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR ___

△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C P

NEXT ASSY | USED ON
APPLICATION

MATERIAL
HARDNESS
HEAT TREAT SPEC
SURFACE COATING
MFG SPEC
MAKE FROM
PROD. CODE

DRAWN Peter G. ...
CHECKED ...
DRAFTING
DESIGN
MATERIALS
PROJECT
COST
FACTORY

EXP MFG | PRELIM PROD. | PROD.

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT · U.S.A.

SCHEMATIC
DC TO DC CONVERTER
BOOSTER 25 WATT

CODE IDENT NO. 73030 | SIZE C | SK63247

SCALE | WEIGHT: | LB | SHEET

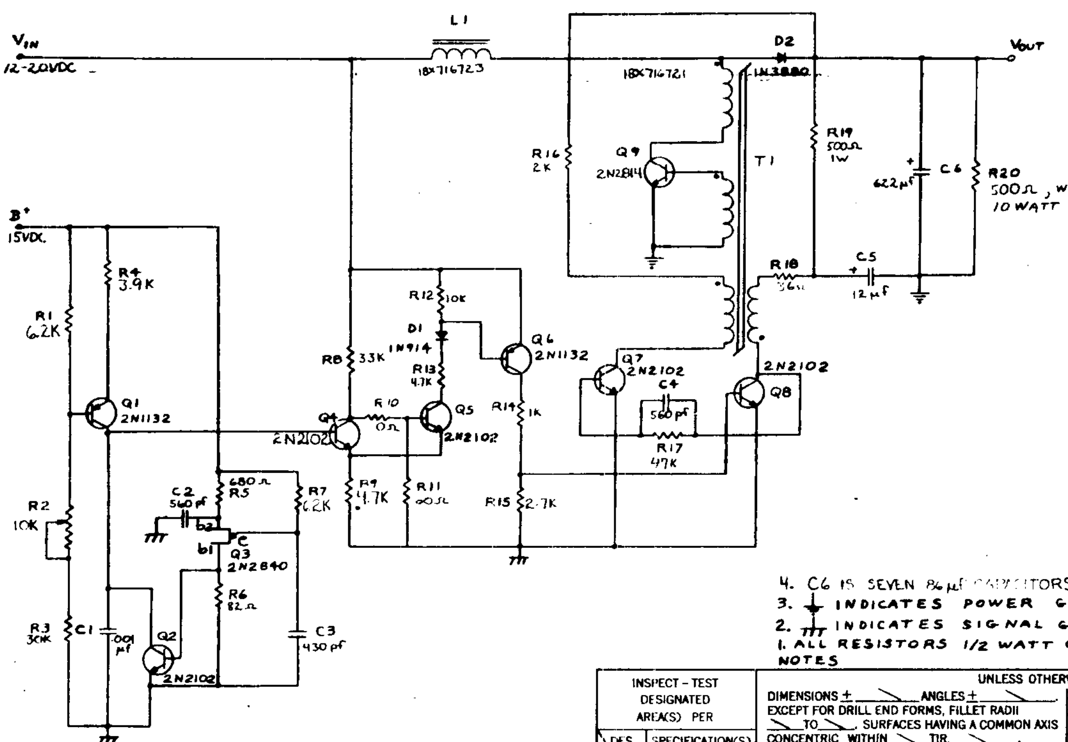
NASA STUDY PROGRAM

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 50 WATT
PARTS LIST NO. SK63248

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6,
5	2N2102	R.C.A.	TRANSISTOR, Q2, Q4, Q5, Q7, Q8
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q3
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q9
1	1N914	TRANSITRON	DIODE, D1
1	1N 3880	WESTINGHOUSE	DIODE, D2
1	.001 μf	C.D. 22A5D1	CAPACITOR, C1
2	560 pf	C.D. 22A3T56JE	CAPACITOR, C2, C4
1	430 pf	C.D. 22A5T43JE	CAPACITOR, C3
1	12 μf	G.E. 29F499	CAPACITOR, C5
7	86 μf	G.E. 69F4856	CAPACITOR, C6
1	10 K	A-B MIL-R-11	RESISTOR, VARIABLE, R2
1	6.2 K	A-B MIL-R-11	RESISTOR, R1
1	30 K	A-B MIL-R-11	RESISTOR, R3
1	3.9 K	A-B MIL-R-11	RESISTOR, R4
1	680 Ω	A-B MIL-R-11	RESISTOR, R5
1	82 Ω	A-B MIL-R-11	RESISTOR, R6
1	62 K	A-B MIL-R-11	RESISTOR, R7
1	33 K	A-B MIL-R-11	RESISTOR, R8
2	4.7 K	A-B MIL-R-11	RESISTOR, R9, R13
1	10 K	A-B MIL-R-11	RESISTOR, R12
1	1 K	A-B MIL-R-11	RESISTOR, R14
1	2.7 K	A-B MIL-R-11	RESISTOR, R15
1	2 K	A-B MIL-R-11	RESISTOR, R16
1	47 K	A-B MIL-R-11	RESISTOR, R17
1	36 Ω	A-B MIL-R-11	RESISTOR, R18
1	500 Ω	A-B MIL-R-11	RESISTOR, 1 WATT, R19
1	500 Ω	CLAROSTAT	RESISTOR, WW, 10 WATT, R20
1	18X 716723	HAMILTON STANDARD	CHOKE, L1
1	18X 716721	HAMILTON STANDARD	TRANSFORMER, T1

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL



SK63248

NOTES
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
2. ⏚ INDICATES SIGNAL GROUND
3. ⏚ INDICATES POWER GROUND
4. C6 IS SEVEN 86μF CAPACITORS IN PARALLEL

INSPECT - TEST DESIGNATED AREA(S) PER	
DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ML AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___, SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR.

△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C ___ P ___

MATERIAL	
HARDNESS	
HEAT TREAT SPEC	
SURFACE COATING	
MFG SPEC	
MAKE FROM	
PROD. CODE	

DRAWN	Peter B. Rosen	1/21/66
CHECKED	R. J. Khan	1/21/66
DRAFTING		
DESIGN		
MATERIALS		
PROJECT	F. Rapoza	1/21/66
COST		
FACTORY		

EXP MFG	PRELIM PROD.	PROD.
4-25-66		

NEXT ASSY	USED ON
APPLICATION	

Hamilton Standard — DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC
DC TO DC CONVERTER
BOOSTER 50 WATT

CODE IDENT NO.	SIZE	
73030	C	SK63248
SCALE:	WEIGHT: LB	SHEET

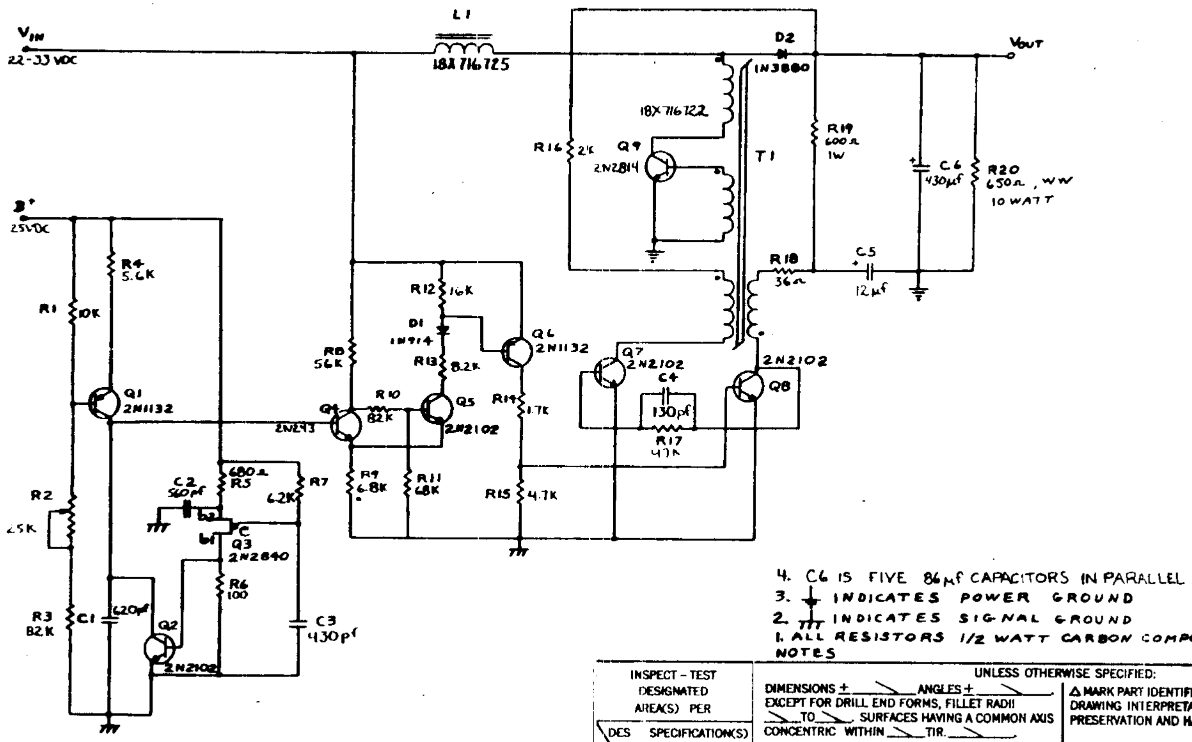
NASA STUDY PROGRAM

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 100 WATT
PARTS LIST NO. SK63249

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6
4	2N2102	R.C.A.	TRANSISTOR, Q2, Q5, Q7, Q8
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q3
1	2N2432	T.I.	TRANSISTOR, Q4
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q9
1	1N914	TRANSITRON	DIODE, D1
1	1N3880	WESTINGHOUSE	DIODE, D2
1	620 pf	C.D. 5A5T62 JE	CAPACITOR, C1
1	560 pf	C.D. 22A3T56 JE	CAPACITOR, C2
1	430 pf	C.D. 22A5T43 JE	CAPACITOR, C3
1	130 pf	C.D. 22A5T13 JE	CAPACITOR, C4
1	12 μf	G.E. 29F499	CAPACITOR, C5
5	86 μf	G.E. 69F485-6	CAPACITOR, C6
1	25 K	A-B MIL-R-11	RESISTOR, VARIABLE, R2
1	10 K	A-B MIL-R-11	RESISTOR, R1
2	82 K	A-B MIL-R-11	RESISTOR, R3, R10
1	5.6 K	A-B MIL-R-11	RESISTOR, R4
1	680 Ω	A-B MIL-R-11	RESISTOR, R5
1	100 Ω	A-B MIL-R-11	RESISTOR, R6
1	6.2 K	A-B MIL-R-11	RESISTOR, R7
1	56 K	A-B MIL-R-11	RESISTOR, R8
1	6.8 K	A-B MIL-R-11	RESISTOR, R9
1	63 K	A-B MIL-R-11	RESISTOR, R11
1	16 K	A-B MIL-R-11	RESISTOR, R12
1	8.2 K	A-B MIL-R-11	RESISTOR, R13
1	1.7 K	A-B MIL-R-11	RESISTOR, R14
1	4.7 K	A-B MIL-R-11	RESISTOR, R15
1	2 K	A-B MIL-R-11	RESISTOR, R16
1	47 K	A-B MIL-R-11	RESISTOR, R17
1	36 Ω	A-B MIL-R-11	RESISTOR, R18
1	600 Ω	A-B MIL-R-11	RESISTOR, 1 WATT, R19
1	650 Ω	CLAROSTAT	RESISTOR, W.W., 10 WATT, R20
1	18X712537	HAMILTON STANDARD	CHOKE, L1
1	18X716722	HAMILTON STANDARD	TRANSFORMER, T1

SYM	DESCRIPTION	DATE	APPROVAL
A	L1 WAS 18X712537	[illegible]	[illegible]



SK63249

A

4. C6 IS FIVE 86μf CAPACITORS IN PARALLEL
3. ⏚ INDICATES POWER GROUND
2. ⏚ INDICATES SIGNAL GROUND
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED

NOTES

INSPECT - TEST DESIGNATED AREA(S) PER

DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___ SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR ___

△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333.
DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C ___ P ___

NEXT ASSY	USED ON
APPLICATION	

MATERIAL	
HARDNESS	
HEAT TREAT SPEC	
SURFACE COATING	
MFG SPEC	
MAKE FROM	
PROD. CODE	

DRAWN	[illegible]	[illegible]
CHECKED	[illegible]	[illegible]
DRAFTING		
DESIGN		
MATERIALS		
PROJECT	[illegible]	[illegible]
COST		
FACTORY		

EXP MFG	PRELIM PROD.	PROD.
[illegible]		

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT · U.S.A.

SCHEMATIC DC TO DC CONVERTER BOOSTER 100 WATT

CODE IDENT NO.	SIZE	
73030	C	SK63249

SCALE: ___ WEIGHT: ___ LB SHEET

NASA STUDY PROGRAM

PHASE I

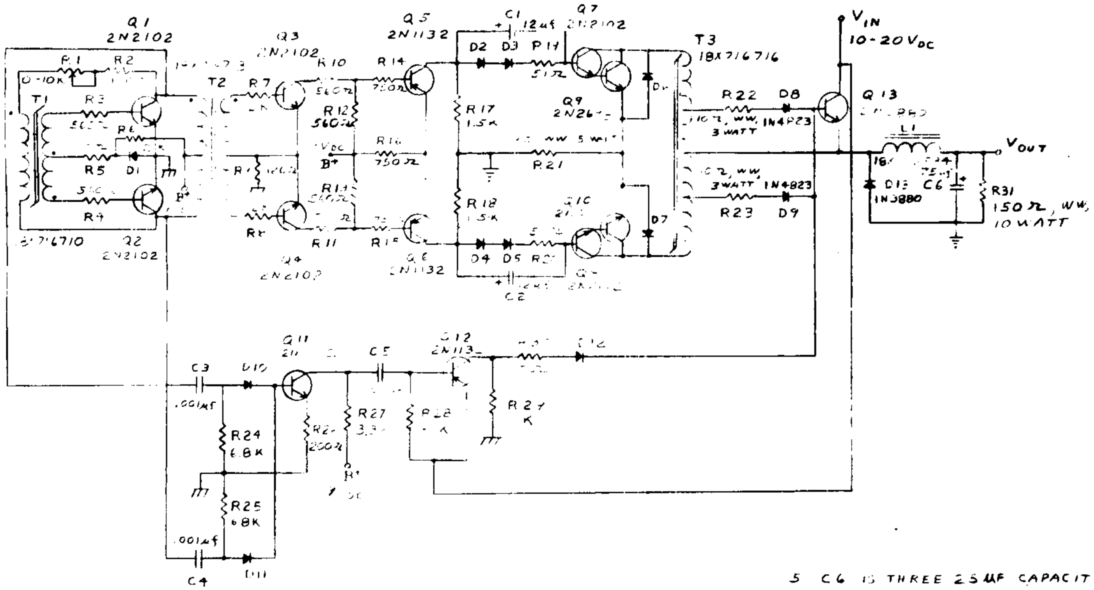
CHOPPERS

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER CHOPPER, 10 WATT
PARTS LIST NO. 5K63242

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
7	2N2102	R.C.A.	TRANSISTOR, Q1, Q2, Q3, Q4, Q7, Q8, Q11
3	2N1132	FAIRCHILD	TRANSISTOR, Q5, Q6, Q12
2	2N2698	SOLITRON	TRANSISTOR, Q9, Q10
1	2N2880	SOLITRON	TRANSISTOR, POWER, Q13
10	1N914	TRANSITRON	DIODE, D1 — D7, D10, D11, D12
2	1N4823	WESTINGHOUSE	DIODE, D8, D9
1	1N3880	WESTINGHOUSE	DIODE, D13
2	12 μf	G.E. 29F499	CAPACITOR, C1, C2
2	.001 μf	GUIDEMAN XHF-2537	CAPACITOR, C3, C4
1	.002 μf	GUIDEMAN XHF-2536	CAPACITOR, C5
3	25 μf	G.E. 69F260G6	CAPACITOR, C6
1	10 K	A-B MIL-R-11	RESISTOR, VARIABLE, R1
1	100 Ω	A-B MIL-R-11	RESISTOR, R2
6	560 Ω	A-B MIL-R-11	RESISTOR, R3, R4, R10, R11, R12, R13
1	62 K	A-B MIL-R-11	RESISTOR, R6
2	12 K	A-B MIL-R-11	RESISTOR, R7, R8
1	120 Ω	A-B MIL-R-11	RESISTOR, R9
3	750 Ω	A-B MIL-R-11	RESISTOR, R14, R15, R16
2	1.5 K	A-B MIL-R-11	RESISTOR, R17, R18
2	51 Ω	A-B MIL-R-11	RESISTOR, R19, R20
1	9 Ω	TEPRO TS	RESISTOR, WW, 5 WATT, R21
2	10 Ω	TEPRO TS	RESISTOR, WW, 3 WATT, R22, R23
2	6.8K	A-B MIL-R-11	RESISTOR, R24, R25
1	200 Ω	A-B MIL-R-11	RESISTOR, R26
1	3.3 K	A-B MIL-R-11	RESISTOR, R27
1	4.7 K	A-B MIL-R-11	RESISTOR, R28
1	11 K	A-B MIL-R-11	RESISTOR, R29
1	150 Ω	CLAROSTAT	RESISTOR, WW, 10 WATT, R31
1	18X712534	HAMILTON STANDARD	FILTER CHOKE, L1
1	18X716710	HAMILTON STANDARD	TRANSFORMER, T1
1	18X716713	HAMILTON STANDARD	TRANSFORMER, T2
1	18X716716	HAMILTON STANDARD	TRANSFORMER, T3

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL



SK63242

NOTES
1 ALL DIODES 1N914 EXCEPT WHERE NOTED
2 ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
3 ⏊ INDICATES SIGNAL GROUND
4 ⏚ INDICATES POWER GROUND
5 C6 IS THREE 25μF CAPACITORS IN PARALLEL

INSPECT - TEST DESIGNATED AREA(S) PER	
DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___. SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR ___.
△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333.
DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C ___ P ___

NEXT ASSY	USED ON
APPLICATION	

MATERIAL	
HARDNESS	
HEAT TREAT SPEC	
SURFACE COATING	
MFG SPEC	
MAKE FROM	
PROD. CODE	

DRAWN	Peter A. Arcari	1/3/66
CHECKED	Richard T. Lane	1/24/66
DRAFTING		
DESIGN		
MATERIALS		
PROJECT	F. Yagner	1/25/66
COST		
FACTORY		

EXP MFG	PRELIM PROD	PROD.
4-20-66		

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC
DC TO DC CONVERTER
CHOPPER, 10 WATT

CODE IDENT NO.	SIZE	
73030	C	SK63242
SCALE:	WEIGHT: LB	SHEET

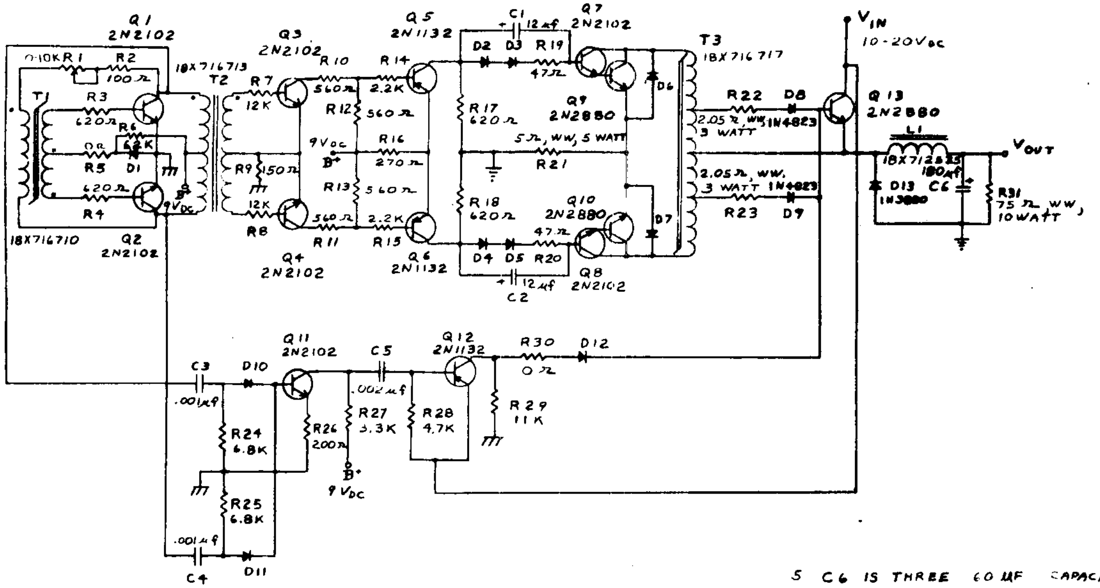
NASA STUDY PROGRAM

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, CHOPPER, 25 WATT
PARTS LIST NO. SK63243

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
7	2N2102	R.C.A.	TRANSISTOR, Q1, Q2, Q3, Q4, Q7, Q8, Q11
3	2N1132	FAIRCHILD	TRANSISTOR, Q5, Q6, Q12
3	2N2880	SOLITRON	TRANSISTOR, POWER, Q9, Q10, Q13
10	1N914	TRANSITRON	DIODE D1 – D7, D10, D11, D12
2	1N4823	WESTINGHOUSE	DIODE, D8, D9
1	1N3880	WESTINGHOUSE	DIODE, D13
2	12 μf	G.E. 29F499	CAPACITOR, C1, C2
2	.001 μf	GUIDEMAN XHF-2537	CAPACITOR, C3, C4
1	.002 μf	GUIDEMAN XHF-2536	CAPACITOR, C5
3	60 μf	G.E. 69F36066	CAPACITOR, C6
1	10 K	A-B MIL-R-11	RESISTOR, VARIABLE, R1
1	100 Ω	A-B MIL-R-11	RESISTOR, R2
4	620 Ω	A-B MIL-R-11	RESISTOR, R3, R4, R17, R18
1	62 K	A-B MIL-R-11	RESISTOR,* R6
2	12 K	A-B MIL-R-11	RESISTOR, R7, R8
1	150 Ω	A-B MIL-R-11	RESISTOR, R9
4	560 Ω	A-B MIL-R-11	RESISTOR, R10, R11, R12, R13
2	2.2 K	A-B MIL-R-11	RESISTOR, R14, R15
1	270 Ω	A-B MIL-R-11	RESISTOR, R16
2	47 Ω	A-B MIL-R-11	RESISTOR, R19, R20
1	5 Ω	TEPRO TS	RESISTOR, WW, 5 WATT, R21
2	2.05 Ω	TEPRO TS	RESISTOR, WW, 3 WATT, R22, R23
2	6.8K	A-B MIL-R-11	RESISTOR, R24, R25
1	200 Ω	A-B MIL-R-11	RESISTOR, R26
1	3.3 K	A-B MIL-R-11	RESISTOR, R27
1	4.7 K	A-B MIL-R-11	RESISTOR, R28
1	11 K	A-B MIL-R-11	RESISTOR, R29
1	75 Ω	CLAROSTAT	RESISTOR, WW, 10 WATT, R31
1	18X712535	HAMILTON STANDARD	FILTER CHOKE, L1
1	18X716710	HAMILTON STANDARD	TRANSFORMER, T1
1	18X716713	HAMILTON STANDARD	TRANSFORMER, T2
1	18X716717	HAMILTON STANDARD	TRANSFORMER, T3

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL



SK63243

NOTES

1 ALL DIODES 1N914 EXCEPT WHERE NOTED

2 ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED

3 ⏚ INDICATES SIGNAL GROUND

4 ⏚ INDICATES POWER GROUND

5 C6 IS THREE 60 μF CAPACITORS IN PARALLEL

INSPECT - TEST DESIGNATED AREA(S) PER		UNLESS OTHERWISE SPECIFIED:				
DES	SPECIFICATION(S)	DIMENSIONS ± ___ ANGLES ± ___ EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___ SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR ___	△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C ___ P ___	NEXT ASSY	USED ON	
				APPLICATION		
A		MATERIAL	DRAWN / CHECKED / DRAFTING / DESIGN / MATERIALS / PROJECT / COST / FACTORY	Hamilton Standard — WINDSOR LOCKS, CONNECTICUT · U.S.A.		
B				SCHEMATIC DC TO DC CONVERTER CHOPPER 25 WATT		
C		HARDNESS				
		HEAT TREAT SPEC				
ALL AREAS		SURFACE COATING	EXP MFG / PRELIM PROD. / PROD.	CODE IDENT NO. 73030	SIZE C	SK63243
ALL AREAS		MFG SPEC / MAKE FROM / PROD. CODE		SCALE:	WEIGHT: LB	SHEET

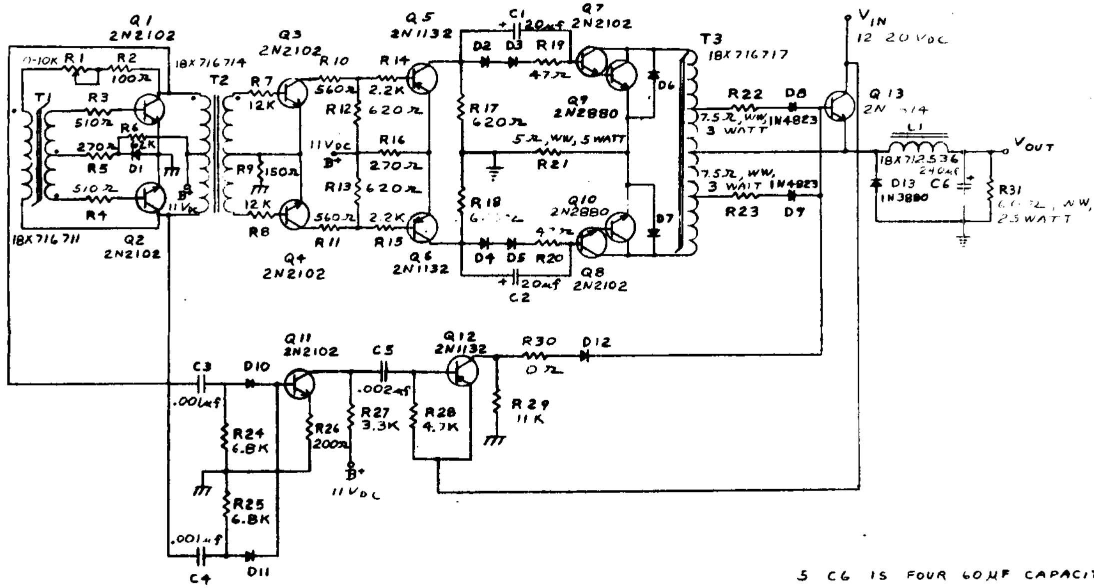
NASA STUDY PROGRAM

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, CHOPPER, 50 WATT
PARTS LIST NO. SK63244

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
7	2N2102	R.C.A.	TRANSISTOR, Q1, Q2, Q3, Q4, Q7, Q8, Q11
3	2N1132	FAIRCHILD	TRANSISTOR, Q5, Q6, Q12
2	2N2880	SOLITRON	TRANSISTOR, POWER, Q9, Q10
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q13
10	1N914	TRANSITRON	DIODE, D1-D7, D10, D11, D12
2	1N4823	WESTINGHOUSE	DIODE, D8, D9
1	1N3880	WESTINGHOUSE	DIODE, D13
2	20 µf	TANSITOR W20-85D3K	CAPACITOR, C1, C2
2	.001 µf	GUIDEMAN XHF-2537	CAPACITOR, C3, C4
1	.002 µf	GUIDEMAN XHF-2536	CAPACITOR, C5
4	60 µf	G.E. 69F36066	CAPACITOR, C6
1	10 K	A-B MIL-R-11	RESISTOR, VARIABLE, R1
1	100 Ω	A-B MIL-R-11	RESISTOR, R2
2	510 Ω	A-B MIL-R-11	RESISTOR, R3, R4
2	270 Ω	A-B MIL-R-11	RESISTOR, R5, R16
1	62 K	A-B MIL-R-11	RESISTOR, R6
2	12 K	A-B MIL-R-11	RESISTOR, R7, R8
1	150 Ω	A-B MIL-R-11	RESISTOR, R9
2	560 Ω	A-B MIL-R-11	RESISTOR, R10, R11
4	620 Ω	A-B MIL-R-11	RESISTOR, R12, R13, R17, R18
2	2.2 K	A-B MIL-R-11	RESISTOR, R14, R15
2	47 Ω	A-B MIL-R-11	RESISTOR, R19, R20
1	5 Ω	TEPRO TS	RESISTOR, WW, 5 WATT, R21
2	7.5 Ω	TEPRO TS 6546	RESISTOR, WW, 3 WATT, R22, R23
2	6.8 K	A-B MIL-R-11	RESISTOR, R24, R25
1	200 Ω	A-B MIL-R-11	RESISTOR, R26
1	3.3 K	A-B MIL-R-11	RESISTOR, R27
1	4.7 K	A-B MIL-R-11	RESISTOR, R28
1	11 K	A-B MIL-R-11	RESISTOR, R29
1	60 Ω	CLAROSTAT	RESISTOR, WW, 25 WATT, R31
1	18X712536	HAMILTON STANDARD	FILTER CHOKE, L1
1	18X716711	HAMILTON STANDARD	TRANSFORMER, T1
1	18X716714	HAMILTON STANDARD	TRANSFORMER, T2
1	18X716717	HAMILTON STANDARD	TRANSFORMER, T3

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL



SK63244

NOTES
1 ALL DIODES 1N914 EXCEPT WHERE NOTED
2 ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
3 ⫛ INDICATES SIGNAL GROUND
4 ⏚ INDICATES POWER GROUND
5 C6 IS FOUR 60μF CAPACITORS IN PARALLEL

INSPECT – TEST DESIGNATED AREA(S) PER	
DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___. SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR.

△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C___P___

NEXT ASSY	USED ON
APPLICATION	

MATERIAL	
HARDNESS	
HEAT TREAT SPEC	
SURFACE COATING	
MFG SPEC	
MAKE FROM	
PROD. CODE	

DRAWN	Peter B. Ganci	1/3/66
CHECKED	Richard [illegible]	1/2/66
DRAFTING		
DESIGN		
MATERIALS		
PROJECT	[illegible]	1/25/66
COST		
FACTORY		

EXP MFG	PRELIM PROD.	PROD.
[illegible]		

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC DC TO DC CONVERTER CHOPPER 50 WATT

CODE IDENT NO.	SIZE	
73030	C	SK63244
SCALE:	WEIGHT: LB	SHEET

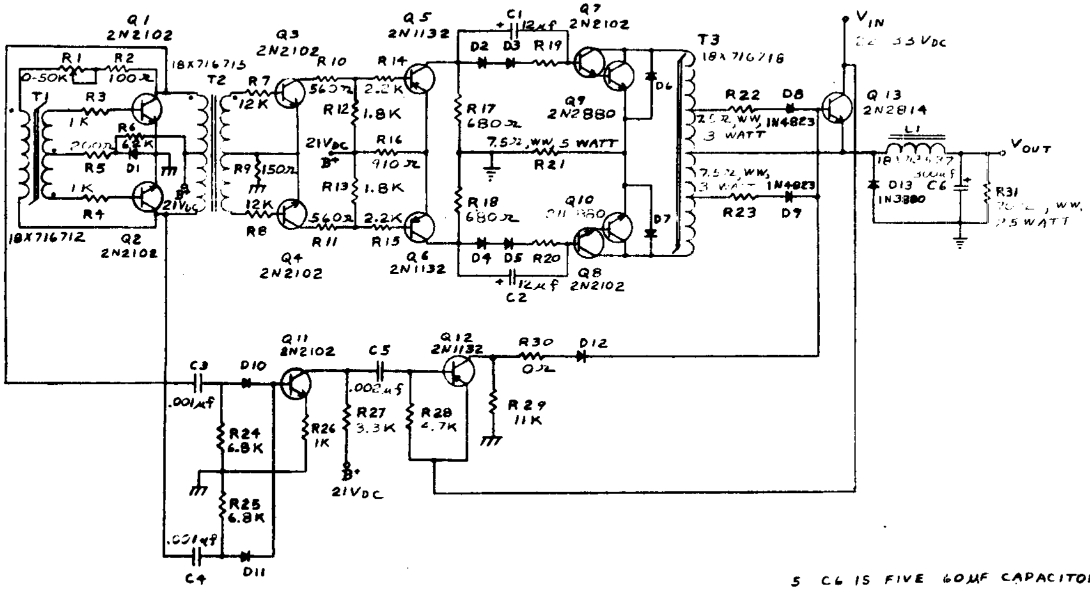
NASA STUDY PROGRAM

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR D.C. TO D.C. CONVERTER, CHOPPER, 100 WATT
PARTS LIST NO. SK63245

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
7	2N2102	R.C.A.	TRANSISTOR, Q1, Q2, Q3, Q4, Q7, Q8, Q11
3	2N1132	FAIRCHILD	TRANSISTOR, Q5, Q6, Q12
2	2N2880	SOLITRON	TRANSISTOR, POWER, Q9, Q10
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q13
10	1N914	TRANSITRON	DIODE, D1-D7, D10, D11, D12
2	1N4823	WESTINGHOUSE	DIODE, D8, D9
1	1N3880	WESTINGHOUSE	DIODE, D13
2	12 µf	G.E. 29F499	CAPACITOR, C1, C2
2	.001 µf	GUIDEMAN XHF-2537	CAPACITOR, C3, C4
1	.002 µf	GUIDEMAN XHF-2536	CAPACITOR, C5
5	60 µf	G.E. 69F36066	CAPACITOR, C6
1	50 K	A-B MIL-R-11	RESISTOR, VARIABLE, R1
1	100 Ω	A-B MIL-R-11	RESISTOR, R2
3	1 K	A-B MIL-R-11	RESISTOR, R3, R4, R26
1	200 Ω	A-B MIL-R-11	RESISTOR, R5
1	62 K	A-B MIL-R-11	RESISTOR, R6
2	12 K	A-B MIL-R-11	RESISTOR, R7, R8
1	150 Ω	A-B MIL-R-11	RESISTOR, R9
2	560 Ω	A-B MIL-R-11	RESISTOR, R10, R11
2	1.8 K	A-B MIL-R-11	RESISTOR, R12, R13
2	2.2 K	A-B MIL-R-11	RESISTOR, R14, R15
1	910 Ω	A-B MIL-R-11	RESISTOR, R16
2	680 Ω	A-B MIL-R-11	RESISTOR, R17, R18
2	47 Ω	A-B MIL-R-11	RESISTOR, R19, R20
1	7.5 Ω	TEPRO TS 6546	RESISTOR, WW, 5 WATT, R21
2	7.5 Ω	TEPRO TS 6546	RESISTOR, WW, 3 WATT, R22, R23
2	6.8 K	A-B MIL-R-11	RESISTOR, R24, R25
1	3.3 K	A-B MIL-R-11	RESISTOR, R27
1	4.7 K	A-B MIL-R-11	RESISTOR, R28
1	11 K	A-B MIL-R-11	RESISTOR, R29
1	70 Ω	CLAROSTAT	RESISTOR, WW, 25 WATT, R31
1	18X712537	HAMILTON STANDARD	FILTER CHOKE, L1
1	18X716712	HAMILTON STANDARD	TRANSFORMER, T1
1	18X716715	HAMILTON STANDARD	TRANSFORMER, T2
1	18X716718	HAMILTON STANDARD	TRANSFORMER, T3

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL



NOTES

1 ALL DIODES 1N914 EXCEPT WHERE NOTED

2 ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED

3 ⏚ INDICATES SIGNAL GROUND

4 ⏚ INDICATES POWER GROUND

5 C6 IS FIVE 60μF CAPACITORS IN PARALLEL

SK63245

INSPECT - TEST DESIGNATED AREA(S) PER

DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ANGLES ± EXCEPT FOR DRILL END FORMS, FILLET RADII TO . SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN TIR.
△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C P

NEXT ASSY	USED ON
APPLICATION	

MATERIAL
HARDNESS
HEAT TREAT SPEC
SURFACE COATING
MFG SPEC
MAKE FROM
PROD. CODE

DRAWN	Peter G. Garcia	1/3/66
CHECKED	Richard T. Lane	1/21/66
DRAFTING		
DESIGN		
MATERIALS		
PROJECT		1/25/66
COST		
FACTORY		

EXP MFG	PRELIM PROD.	PROD.

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC
DC TO DC CONVERTER
CHOPPER 100 WATT

CODE IDENT NO.	SIZE	
73030	C	SK63245
SCALE:	WEIGHT: LB	SHEET

NASA STUDY PROGRAM

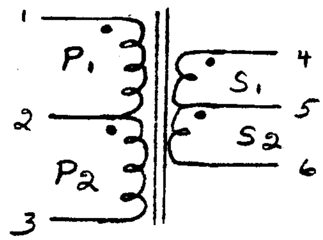
PHASE I

MAGNETICS DRAWINGS

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 12/30/65

P/N 18x 716713 TYPE: 10W AND 25W COUPLING XFMR USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

	Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
BIFILAR	P1	597507	34	10.0'	178	1-2	2.5 ±20%
	P2	597507	34	10.0'	178	2-3	2.5 ±20%
							± %
BIFILAR	S1	597507	34	5.0'	60	4-5	1.20 ±20%
	S2	597507	34	5.0'	60	5-6	1.20 ±20%
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN; $P_1 - P_2$ AND $S_1 - S_2$ BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR. 118D550-4Q DELTAMAX BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 8 in.~~ SELF LEADS - MIN. LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER - Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 9 VRMS @ 3[illegible] KC [illegible] WAVE APPLIED TO TERMINALS 1-2, MEASURE 9VRMS 2-3, AND 3.04 VRMS 4-5 AND 5-6.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

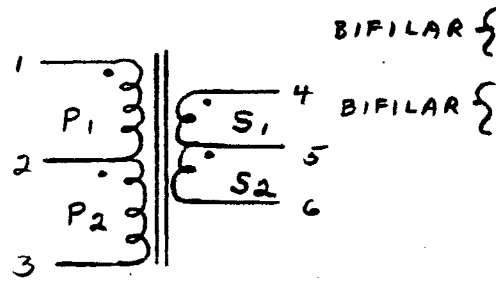
1. TAG LEADS WITH TERMINAL NUMBERS

Engineer	[signature]	Date: 12/30/65
Approval		Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 12/30/65

P/N HS 716714 | TYPE: SOW COUPLING XFMR. | USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
P_1	597507	34	12.0'	218	1-2	3.0 ±20%
P_2	597507	34	12.0	218	2-3	3.0 ±20%
						± %
S_1	597507	34	5.0'	60	4-5	1.21 ±20%
S_2	597507	34	5.0'	60	5-6	1.21 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN ; P_1-P_2 + S_1+S_2 BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR. 1118D250-42 DELTAMAX BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 8 in.~~ SELF LEADS - MIN. LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 11 VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS 1-2, MEASURE 11 VRMS 2-3, AND 3.02 VRMS 4-5 AND 5-6,

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

1. TAG LEADS WITH TERMINAL NUMBERS

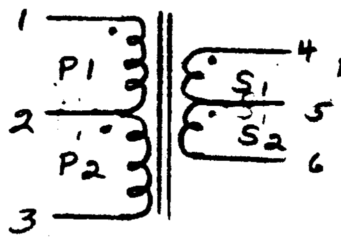
Engineer Peter R. Para Date: 12/30/65

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 12/30/65

P/N IRx 716715 | TYPE: 100W COUPLING XFMR | USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

	Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
BIFILAR	P1	597507	34	30.0'	416	1-2	6.1 ±20%
	P2	597507	34	30.0'	416	2-3	6.1 ±20%
							± %
BIFILAR	S1	597507	34	6.0'	60	4-5	1.48 ±20%
	S2	597517	34	6.0'	60	5-6	1.48 ±20%
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN; P_1-P_2 + S_1-S_2 BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR. 111D250-42 DELTAMAX BOBBIN TOROID

BULLDN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 8 in.~~ SELF LEADS, - MIN. LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 21 VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS 1-2, MEASURE 21 VRMS 2-3, AND 3.03 VRMS 4-5 AND 5-6.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

1. WIND TIGHT!
2. TAG LEADS WITH TERMINAL NUMBERS

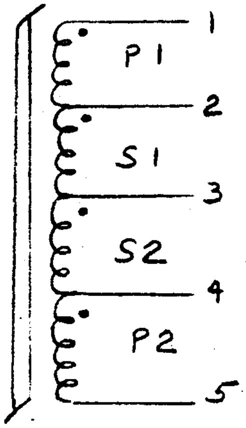
Engineer Peter R. Parise Date: 12/30/65

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 1/20/66

P/N 18x 716716 | TYPE: 10 WATT DRIVER-CHOPPER | USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



BIFILAR (P1, P2)

BIFILAR (S1, S2)

Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
P1	597507	27	3.0'	39	1-2	0.137 ±20%
P2	597507	27	3.0'	39	4-5	0.137 ±20%
						± %
S1	597507	27	2.0'	11	2-3	0.085 ±20%
S2	597507	27	2.0'	11	3-4	0.085 ±20%

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN, P1-P2 AND S1-S2 BIFILAR WOUND.

INSULATION NONE

CORE ARNOLD ENGR. 118D250-42 DELTAMAX BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 8 in.~~ SELF LEADS — MIN. LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 1Vrms @ 30KC SINE WAVE APPLIED TO TERMINALS 1-3, MEASURE 1Vrms 3-5, AND 0.22 Vrms 2-3 AND 3-4.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

TAG LEADS WITH TERMINAL NUMBERS

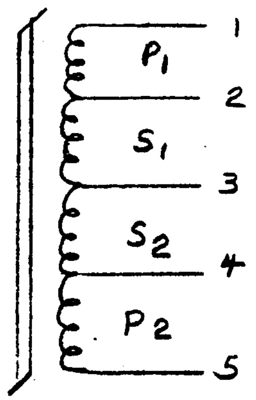
Engineer Peter R Parisi Date: 1/20/66

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET — DATE: 1/20/66

P/N 15x 716717 — TYPE: 25W+50W DRIVER CHOPPER — USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

	Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
BIFILAR	P1	597507	26	3.0'	38	1-2	0.105 ±20%
	P2	597507	26	3.0'	38	4-5	0.105 ±20%
							± %
BIFILAR	S1	597507	26	2.0'	12	2-3	0.065 ±20%
	S2	597507	26	2.0'	12	3-4	0.065 ±20%
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %
							± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN; P1-P2 AND S1-S2 BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR. 118D250-42 DELTAMAX BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 8 in.~~ SELF LEADS MIN. LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NOT APPLICABLE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 1 VRMS @ 30KC SINEWAVE APPLIED TO TERMINALS 1-3, MEASURE 1 VRMS 3-5, AND 0.24 VRMS 2-3 AND 3-4.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

1. TAG LEADS WITH TERMINAL NUMBERS

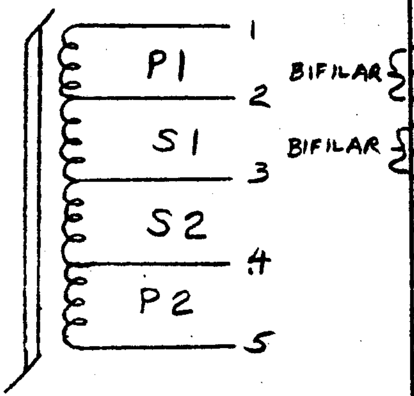
Engineer Peter R Parisi Date: 1/20/66

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 1/20/66

P/N 1Hx 716718 | TYPE: 100 WATT DRIVER CHOPPER | USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
P1	597507	27	6.0'	122	1-2	0.285 ±20%
P2	597507	27	6.0'	122	4-5	0.285 ±20%
						± %
S1	597507	28	3.0'	19	2-3	0.147 ±20%
S2	597507	28	3.0'	19	3-4	0.147 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN; P1-P2 AND S1-S2 BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR, 111 D250-42 DELTAMAX BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 8 in.~~ SELF LEADS - MIN LENGTH 5 IN

ASSEMBLY NOT APPLICABLE

IMPREGNATION NOT APPLICABLE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 4VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS 1-3, MEASURE 4VRMS 3-5, AND 0.54 VRMS 2-3 AND 3-4.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

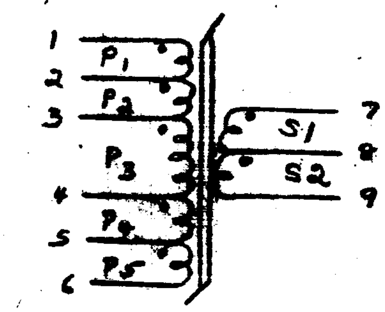
TAG LEADS WITH TERMINAL NUMBERS

Engineer Peter R Poirer Date: 1/20/66
Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 12/30/65

P/N 716 710 TYPE: 10W AND 25W OSCILLATOR XFMR USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
P1	597507	32	2'0"	10	1-2	0.28 ±20%
P2	↓	↓	2'0"	10	2-3	0.28 ±20%
P3			11'0"	200	3-4	1.70 ±20%
P4			2'0"	10	4-5	0.28 ±20%
P5			2'0"	10	5-6	0.28 ±20%
						± %
S1	597507	32	5'0"	70	7-8	0.76 ±20%
S2	597507	32	5'0"	70	8-9	0.76 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN; S1 – S2 BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR. 111P250-42 MOLYPERMALLOY BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 5 in.~~ SELF LEADS – MIN. LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER– Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NO LOAD WITH 1 VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS 1-6, MEASURE 0.835 VRMS 3-4, AND 0.292 VRMS 7-8 AND 8-9.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

1) TAG LEADS WITH TERMINAL NUMBERS

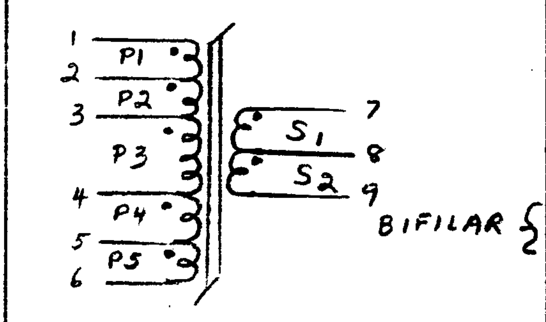
Engineer Peter R. Caroni Date: 12/30/65

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 12/30/65

P/N Hx 716711 TYPE: 50W OSCILLATOR XFMR. USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
P1	597507	32	2.0'	10	1-2	0.22 ±20%
P2			2.0'	10	2-3	0.22 ±20%
P3			12.0'	210	3-4	1.82 ±20%
P4			2.0'	10	4-5	0.22 ±20%
P5			2.0'	10	5-6	0.22 ±20%
						± %
S1	597507	32	5.0'	62	7-8	0.750 ±20%
S2	597507	32	5.0'	62	8-9	0.750 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN; S_1-S_2 BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR. 111P250-42 MOLYPERMALLOY BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 8 in.~~ SELF LEADS - MIN LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NOT APPLICABLE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 1VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS 1-6, MEASURE 0.249 VRMS 7-8 AND 8-9, AND 0.84 VRMS 3-4.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

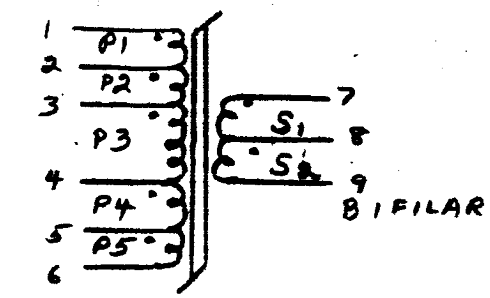
REMARKS
1. TAG LEADS WITH TERMINAL NUMBERS

Engineer Peter R. Parsi Date: 12/30/65
Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 12/30/65

P/N [illegible] 716719 [illegible] 100 W OSCILLATOR XFMR. USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
P1	597507	34	3.0'	25	1-2	0.63 ±20%
P2			3.0'	25	2-3	0.63 ±20%
P3			30.0'	450	3-4	6.3 ±20%
P4			3.0'	25	4-5	0.63 ±20%
P5			3.0'	25	5-6	0.63 ±20%
						± %
S1	597507	34	6.0'	70	7-8	1.40 ±20%
S2	597507	34	6.0'	70	8-9	1.40 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN; S_1-S_2 BIFILAR WOUND

INSULATION NONE

CORE ARNOLD ENGR. 111P250-42 MOLY PERMALLOY BOBBIN TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~min. length 2 in.~~ SELF LEADS - MIN. LENGTH 5 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NOT APPLICABLE

OTHER - Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD **VOLTAGE** WITH 1VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS 1-6, MEASURE 0.82VRMS 3-4, AND 0.127 VRMS 7-8 AND 8-9.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

1. WIND TIGHT
2. TAG LEADS WITH TERMINAL NUMBERS

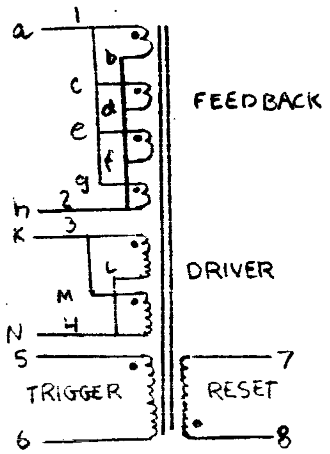
Engineer Peter P. Parga Date: 12/30/65
Approval Date:

HSER 4167

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 1/20/66

P/N 18x 716719 TYPE: 10W DRIVER-BOOSTER USED ON: NASA [illegible]

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	32	[illegible]	86	7-8	[illegible] ±20%
5-6	597507	32	6'	100	5-6	1.27 ±20%
K-L	597507	[illegible]	2'	[illegible]	3-4	.27[illegible] ±20%
M-N	597507	[illegible]	2'	[illegible]	3-4	[illegible] ±20%
a-b	597507	[illegible]	1'	[illegible]	1-2	[illegible] ±[illegible]%
c-d	597507	[illegible]	1'	2	1-2	[illegible] ±[illegible]%
e-f	597507	[illegible]	1'	[illegible]	1-2	[illegible] ±20%
g-h	597507	[illegible]	1'	2	1-2	.01[illegible] ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN ABOVE - SPREAD WINDINGS [illegible] OF CORE

INSULATION NONE

CORE 115D-250-42, ARNOLD ENG. MOLYPERM[illegible] TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS, MIN. LENGTH [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume .0491 [illegible] Weight .0094 [illegible]

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NO LOAD WITH 0.5VRMS @ 30KC SINE WAVE APPLIED TO [illegible] MEASURE .0625 VRMS 1-2, 5VRMS 5-6, AND [illegible] 7-8

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS TAG LEADS WITH TERMINAL NOS

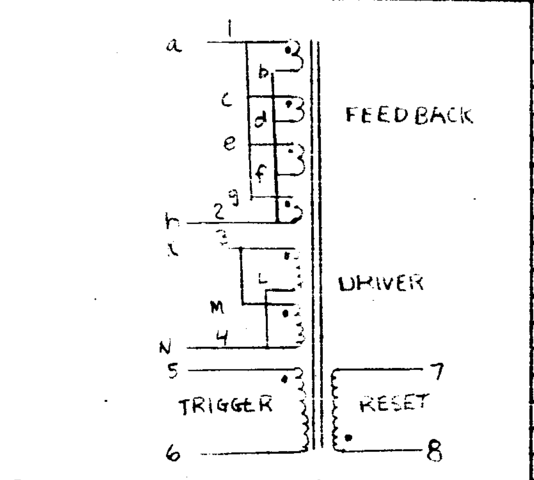
Engineer [illegible] Date: 1/2/66

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET — DATE: 1/26/66

P/N 18x 716720 — TYPE: 25W DRIVER-BOOSTER — USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	32	5'	80	7-8	.676 ±2%
5-6	597507	32	10'	160	5-6	1.43 ±2%
K-L	597507	30	2'	16	3-4	.18 ±2%
M-N	597507	30	2'	16	3-4	.18 ±2%
a-b	597507	24	1'	2	1-2	.006 ±2%
c-d	597507	24	1'	2	1-2	.006 ±2%
e-f	597507	24	1'	2	1-2	.006 ±2%
g-h	597507	24	1'	2	1-2	.006 ±2%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING: WIND IN SEQUENCE SHOWN ABOVE - SPREAD WINDINGS OVER 360° OF CORE

INSULATION: NONE

CORE: 1180-250-42, ARNOLD ENG., MOLYPERMALLOY TOROID

BOBBIN: NOT APPLICABLE

SHIELD: NOT APPLICABLE

TERMINALS min. length 8 in.: [illegible]

ASSEMBLY: NOT APPLICABLE

IMPREGNATION: NONE

OTHER- Dimensions: Length Width Height Volume .0491 in cu Weight .0094 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE: MEASURE AND RECORD

VOLTAGE: NO LOAD [illegible] TERMINALS 3-4, MEASURE .0625 VRMS [illegible] 5-6 [illegible] 7-8

INSULATION RESISTANCE: NOT APPLICABLE

DIELECTRIC: NOT APPLICABLE

INDUCTANCE: NOT APPLICABLE

REMARKS: TAG [illegible] TERMINAL [illegible]

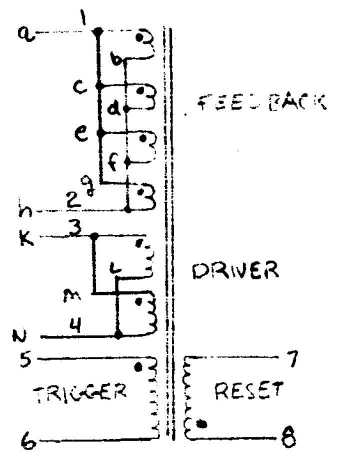
Engineer: [illegible] Date: [illegible]

Approval: Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 1/26/66

P/N 18x 716721 **TYPE:** 50 WATT DRIVER-BOOSTER **USED ON:** NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	31	5'	80	7-8	.56 ±20%
5-6	597507	32	10'	160	5-6	1.8 ±20%
K-L	597507	[illegible]	2'	16	4-3	.13 ±20%
M-N	597507	29	2'	16	4-3	.13 ±20%
a-b	597507	23	1'	2	1-2	.005 ±20%
c-d	597507	23	1'	2	1-2	.005 ±20%
e-f	597507	23	1'	2	1-2	.005 ±20%
g-h	597507	23	1'	2	1-2	.005 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN ABOVE - SPREAD [illegible] OVER [illegible] OF CORE

INSULATION NONE

CORE 118D-250-42, ARNOLD ENG. MOLYPERMALLOY TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS MIN. LENGTH [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume .0491 in cu Weight .0094 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD VOLTAGE WITH 0.5VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS [illegible] MEASURE .0625 VRMS 1-2, 5VRMS 5-6, AND 0.5VRMS 7-8.

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

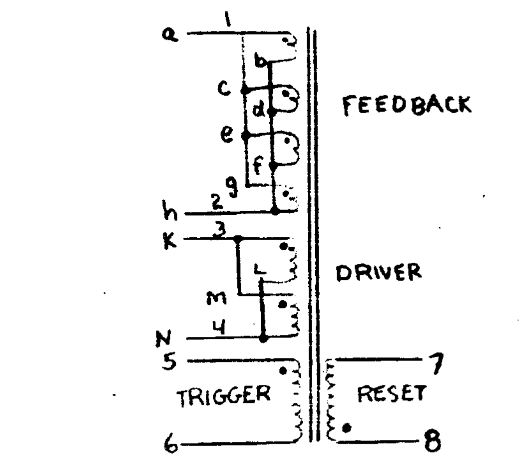
REMARKS TAG LEADS WITH TERMINAL NO.S

Engineer [illegible]	Date: 1/26/66
Approval	Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET	DATE: 1/26/66

P/N 18x 716722 TYPE: 100W DRIVER, BOOSTER USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	31	7'	130	7-8	.041 ±20%
5-6	597507	32	10'	160	5-6	1.5 ±20%
K-L	597507	28	3'	16	3-4	.126 ±20%
M-N	597507	28	3'	16	3-4	.126 ±20%
a-b	597507	23	1'	2	1-2	.005 ±20%
c-d	597507	23	1'	2	1-2	.005 ±20%
e-f	597507	23	1'	2	1-2	.005 ±20%
g-h	597507	23	1'	2	1-2	.005 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING: WIND IN SEQUENCE SHOWN ABOVE - SPREAD WINDINGS OVER 360° OF CORE

INSULATION: NONE

CORE: 118D-250-42, ARNOLD ENG., MOLYPERMALLOY TOROID

BOBBIN: NOT APPLICABLE

SHIELD: NOT APPLICABLE

TERMINALS: min. length 8 in. SELF LEADS - MIN. LENGTH 5"

ASSEMBLY: NOT APPLICABLE

IMPREGNATION: NONE

OTHER - Dimensions: Length Width Height Volume .0491 in cu Weight .0094 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE: MEASURE AND RECORD

VOLTAGE: NO LOAD WITH 0.5VRMS @ 30KC SINE WAVE APPLIED TO TERMINALS 3-4, MEASURE .0025VRMS 1-2, 5VRMS 5-6, AND 4.06 VRMS 7-8

INSULATION RESISTANCE: NOT APPLICABLE

DIELECTRIC: NOT APPLICABLE

INDUCTANCE: NOT APPLICABLE

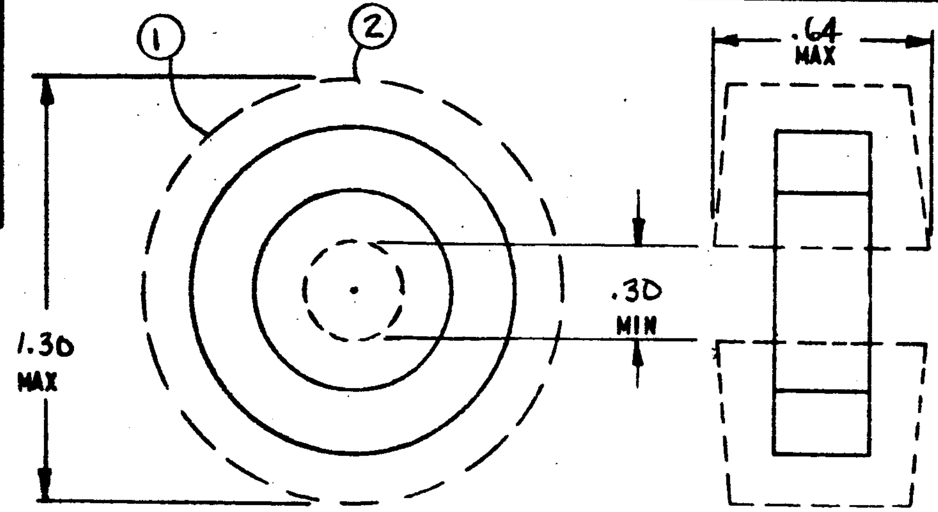
REMARKS: TAG LEADS WITH TERMINAL NO.S

Engineer R Seaver	Date: 1/26/66
Approval	Date:

TRANSFORMER REQUIREMENT

HAMILTON STANDARD
DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT, U. S. A.

003 SHEET 1 OF 1



CORE: MAGNETICS INC
55930-W4

NO. OF CORES PER UNIT 1

CASED CORE DIMENSIONS
ID .555 OD 1.090 H .472

UNMATCHED ☑
MATCHED ☐

WINDING SEQUENCE →	1 ST			
WOUND OVER CORE				
WIRE SIZE AWG 597507	# 22			
TOTAL LENGTH OF WIRE (FT)	19.5'			
TOTAL TURNS	126±0			
TURNS AT TAP	—			
TYPE OF WINDING	FULL			
WINDING SECTION IN DEGREES	360°			
NUMBER OF LAYERS	3			
MAGNET WIRE LEAD LENGTH	6"			
SHUTTLE FOR WINDING MACHINE	—			
WIND ON OR OVER	CORE			
TAPE TO ANCHOR LEADS	NONE			
COIL WRAP	NONE			
PER CENT OF OVERLAP OF WRAP	—			
RESISTANCE IN OHMS (AVE.)	.316 Ω			
WEIGHT OF WIRE LBS. (AVE.)	.039 #			
REMARKS; MANUFACTURE PER HS 2070	START	START	START	START
1) SELF LEADS, NO COIL FINISH	1			
2) With 10 VRMS @ 30 Kc SINE a) $L_X \geq .0021$ Hy with 50 ma DC b) $L_X \geq .00185$ Hy with 1.11 Amp DC	2			
	FINISH	FINISH	FINISH	FINISH

REVISED
APPROVED BY HRS
ISSUED 5-6-66

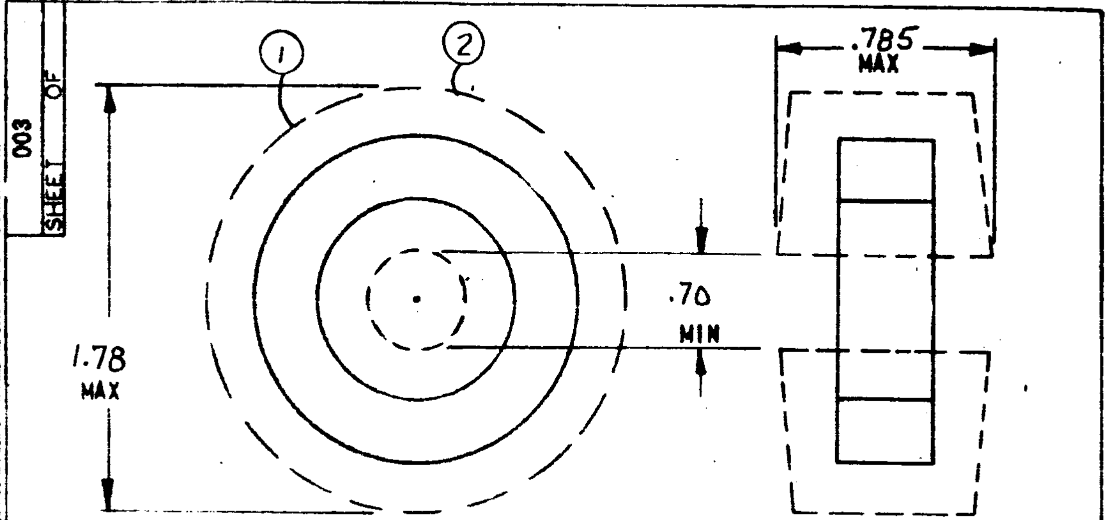
003 SHEET 1 OF 1	PART NO. 1BX712534	TYPE CHOKE	REF NO.

PRODUCT CODE I (10 WATT SUPPLY) NASA STUDY PROGRAM

HSER 4167

TRANSFORMER REQUIREMENT

HAMILTON STANDARD
DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT, U. S. A.



CORE: MAGNETICS INC
55254 - W4

NO. OF CORES PER UNIT 1

CASED CORE DIMENSIONS ID .918 OD 1.602 H .605

UNMATCHED ☑ MATCHED ☐

WINDING SEQUENCE →	1 ST			
WOUND OVER CORE				
WIRE SIZE AWG 597507	#18			
TOTAL LENGTH OF WIRE (FT)	16.5'			
TOTAL TURNS	84 ± 0			
TURNS AT TAP	—			
TYPE OF WINDING	FULL			
WINDING SECTION IN DEGREES	360°			
NUMBER OF LAYERS	2			
MAGNET WIRE LEAD LENGTH	6"			
SHUTTLE FOR WINDING MACHINE	—			
WIND ON OR OVER	CORE			
TAPE TO ANCHOR LEADS	NONE			
COIL WRAP	NONE			
PER CENT OF OVERLAP OF WRAP	—			
RESISTANCE IN OHMS (AVE.)	0.165 Ω			
WEIGHT OF WIRE LBS. (AVE.)	.085 #			
REMARKS; MANUFACTURE PER HS 2070	START 1 FINISH 2	START FINISH	START FINISH	START FINISH

1) SELF LEADS, NO COIL FINISH

2) WITH 10 VRMS @ 30 Kc SINE
a) $L_x \geq .001$ Hy with 60 ma DC
b) $L_x \geq .00074$ Hy with 2.78 A DC

APPROVED BY HRS — REVISED
ISSUED 5-6-66

003 SHEET 1 OF 1	PART NO. 18X712535	TYPE CHOKE	REF. NO.

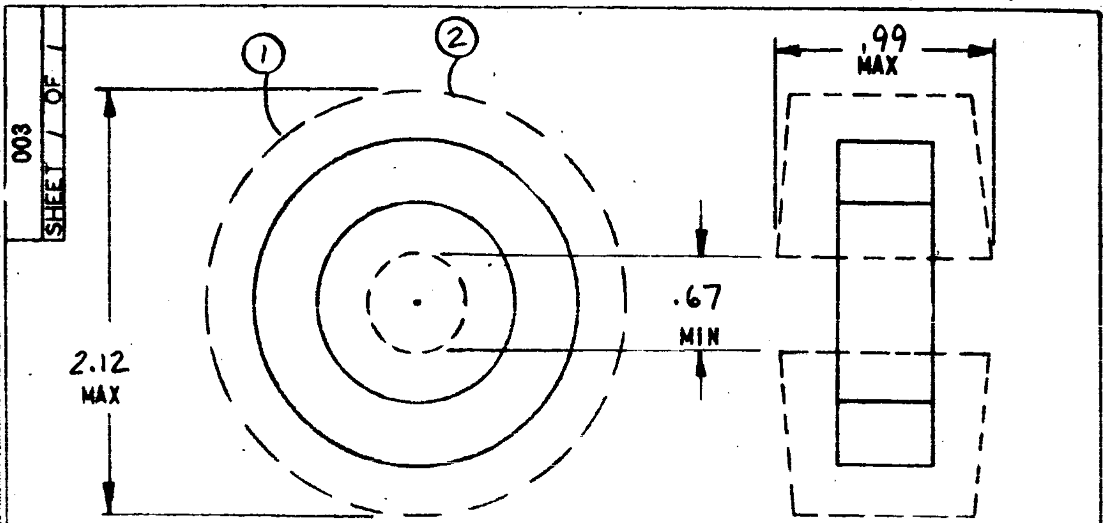
PRODUCT CODE I (25 WATT SUPPLY) NASA STUDY PROGRAM

VII-35

TRANSFORMER REQUIREMENT

HAMILTON STANDARD
DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT, U. S. A.

003 SHEET 1 OF 1



CORE: MAGNETICS INC.
55438-W4

NO. OF CORES PER UNIT 1 — CASED CORE DIMENSIONS ID .918 OD 1.875 H .745 — UNMATCHED ☒ MATCHED ☐

WINDING SEQUENCE →	1 ST			
WOUND OVER CORE				
WIRE SIZE AWG 597507	# 15			
TOTAL LENGTH OF WIRE (FT)	12'			
TOTAL TURNS	49 ± 0			
TURNS AT TAP	—			
TYPE OF WINDING	FULL			
WINDING SECTION IN DEGREES	360°			
NUMBER OF LAYERS	2			
MAGNET WIRE LEAD LENGTH	6"			
SHUTTLE FOR WINDING MACHINE	—			
WIND ON OR OVER	CORE			
TAPE TO ANCHOR LEADS	NONE			
COIL WRAP	NONE			
PER CENT OF OVERLAP OF WRAP	—			
RESISTANCE IN OHMS (AVE.)	.039 Ω			
WEIGHT OF WIRE LBS. (AVE.)	.126 #			
REMARKS; MANUFACTURE PER HS 2070	START 1 ... 2 FINISH	START ... FINISH	START ... FINISH	START ... FINISH

1) SELF LEADS, NO COIL FINISH

2) WITH 10 VRMS @ 30 Kc SINE:
a) $L_x \geq .55$ mhy with .09 AmpDC
b) $L_x \geq .47$ mhy with 4.78 AmpDC

003 SHEET 1 OF 1	PART NO. 18X712536	TYPE CHOKE	REF NO.

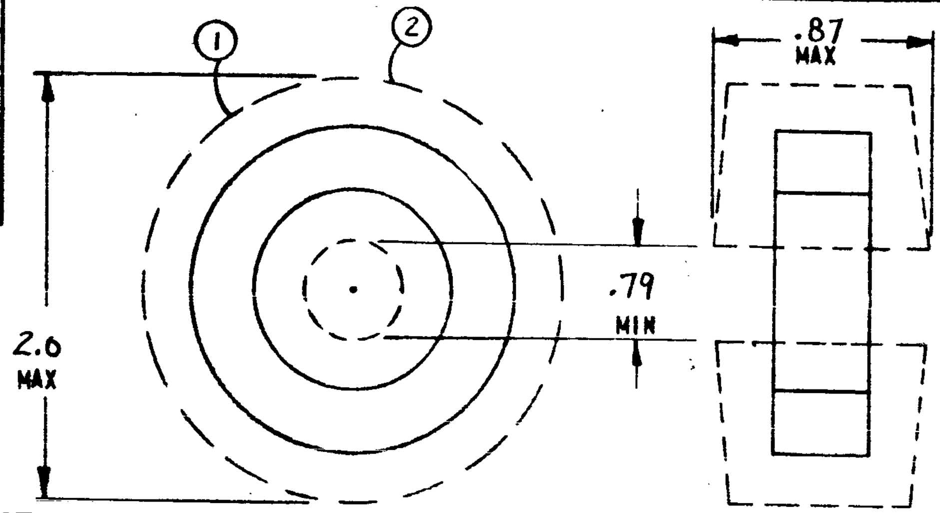
REVISED — APPROVED BY HRS — ISSUED 5-6-66

PRODUCT CODE I (50 WATT SUPPLY) NASA STUDY PROGRAM

TRANSFORMER REQUIREMENT

HAMILTON STANDARD
DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT, U. S. A.

003 SHEET 1 OF 1



CORE: MAGNETICS INC.
55438 - W4

NO. OF CORES PER UNIT 1

CASED CORE DIMENSIONS ID .918 OD 1.875 H .745

UNMATCHED ☒ MATCHED ☐

WINDING SEQUENCE →	1 ST			
WOUND OVER CORE				
WIRE SIZE AWG 597507	# 15			
TOTAL LENGTH OF WIRE (FT)	11'			
TOTAL TURNS	46 ± 0			
TURNS AT TAP	—			
TYPE OF WINDING	FULL			
WINDING SECTION IN DEGREES	360°			
NUMBER OF LAYERS	1			
MAGNET WIRE LEAD LENGTH	6"			
SHUTTLE FOR WINDING MACHINE				
WIND ON OR OVER	CORE			
TAPE TO ANCHOR LEADS	NONE			
COIL WRAP	NONE			
PER CENT OF OVERLAP OF WRAP	—			
RESISTANCE IN OHMS (AVE.)	.035 Ω			
WEIGHT OF WIRE LBS. (AVE.)	0.11 #			
REMARKS; MANUFACTURE PER HS 2070	START ①	START	START	START
1) SELF LEADS, NO COIL FINISH 2) WITH 17 VRMS @ 30 Kc SINE: a) $L_x \geq .5$ mhy with 0.1 Amp DC b) $L_x \geq .43$ mhy with 4.78 Amp DC	② FINISH	FINISH	FINISH	FINISH

003	PART NO.	TYPE	REF NO.
SHEET 1 OF 1	18X712537	CHOKE	

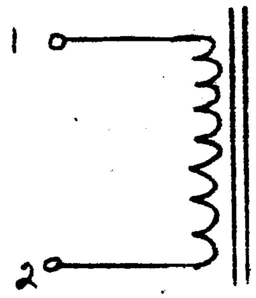
APPROVED BY: HRS ISSUED 5-6-66 REVISED

PRODUCT CODE I (100 WATT SUPPLY) NASA STUDY PROGRAM

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 4/21/66

P/N Ltr 71672 3 | TYPE: CHOKE - 50W BOOSTER | USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
	597507	15	13'	54	1-2	0.034 ± 20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING FULL WINDING

INSULATION NONE

CORE MAGNETICS INC. 55438-W4 TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS ~~Min. Length 6 in.~~ SELF LEADS - MIN. LENGTH 6 in.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE WITH 10VRMS @ 30KC SINE a) $Lx \geq 0.66$ mh 0.09 AMP. DC b) $Lx \geq 0.568$ mh with 4.78 AMP - DC.

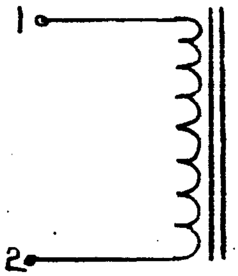
REMARKS

Engineer [signature] Date: 4/21/66
Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET — DATE: 5/6/66

P/N HS 716725 — TYPE: CHOKE, 100 WATT BOOSTER — USED ON: NASA STUDY PROGRAM

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
	597507	#15	13'	54	1-2	.641

MANUFACTURING NOTES

WINDING FULL WINDING

INSULATION NONE

CORE MAGNETICS INC. 55438-W4

[illegible] NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS - MIN LENGTH 6 IN.

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume Weight

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE WITH 17VRMS @ 30KC a) L $\geq$ .75mh .09 aDC
b) L $\geq$ .55mh 4.78 adc

REMARKS

Engineer Richard K Seaver Date: 5/6/66

Approval Date:

PHASE II

BOOSTERS

HAMILTON STANDARD
PARTS LIST

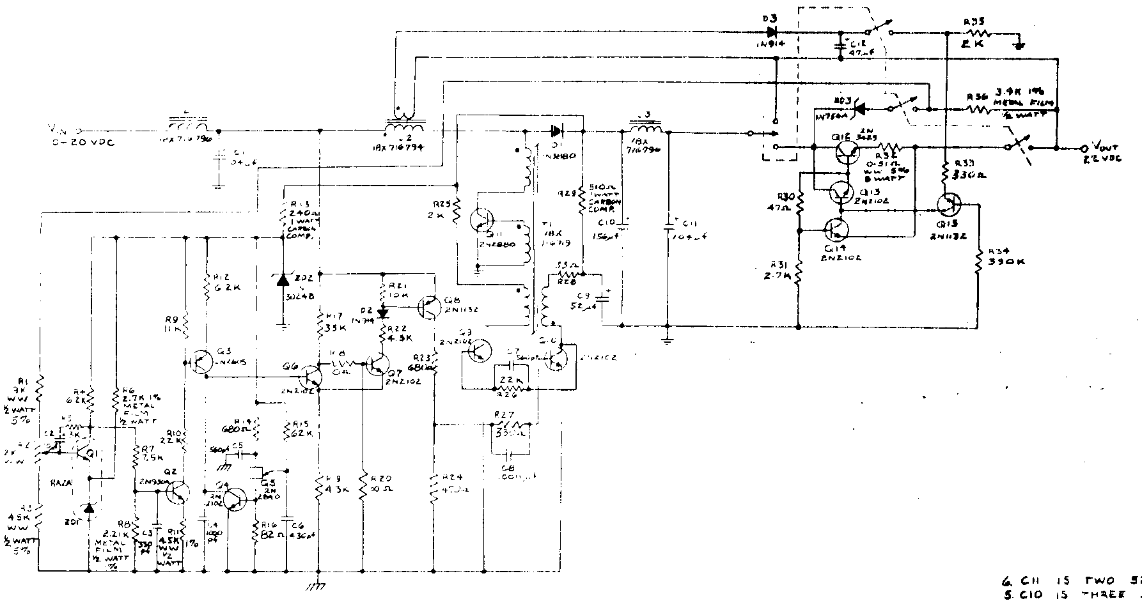
PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 10 WATT
PARTS LIST NO. SK67819

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
1	RA2A	G.E.	TRANSISTOR, REF AMP, Q1, ZD1
1	2N930A	TRANSITRON	TRANSISTOR, Q2
1	2N2605	TRANSITRON	TRANSISTOR, Q3
7	2N2102	R.C.A.	TRANSISTOR, Q4, Q6, Q7, Q9, Q10, Q13, Q14
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q5
2	2N1132	FAIRCHILD	TRANSISTOR, Q8, Q15
1	2N2880	SOLITRON	TRANSISTOR, POWER, Q11
1	2N3429	WESTINGHOUSE	TRANSISTOR, POWER, Q12
1	1N3880	WESTINGHOUSE	DIODE, D1
2	1N914	TRANSITRON	DIODE, D2, D3
1	1N3024B	HOFFMAN	DIODE, ZENER, ZD2
1	1N754A	HOFFMAN	DIODE, ZENER, ZD3
8	52 µf	G.E. 29F352162	CAPACITOR, C1, C9, C10, C11
1	10 µf	T.I. SCM-4-6534114	CAPACITOR, C2
1	330 pf	CD 22A5F33JE	CAPACITOR, C3
1	1000 pf	C.D. 22A5D1	CAPACITOR, C4
2	560 pf	C.D. 22A3F56JE	CAPACITOR, C5, C7
1	430 pf	CD 22A5T43JE	CAPACITOR, C6
1	.0011 µf	C.D. 22A5D11	CAPACITOR, C8
1	47 µf	G.E. 69F121	CAPACITOR, C12
1	9K	TEPRO	RESISTOR, WW, ½ WATT 5%, R1
1	2K	BOURNS	RESISTOR, VAR., WW, R2
1	4.5K	TEPRO	RESISTOR, WW ½ WATT 1%, R3
2	6.2K	AB MIL-R-11	RESISTOR, R4, R12
1	3K	A.B. MIL-R-11	RESISTOR, R5
1	2.7K	MEPCO	RESISTOR, METAL FILM, ½ WATT 1%, R6
1	7.5K	A.B. MIL-R-11	RESISTOR, R7
1	2.21K	MEPCO	RESISTOR, METAL FILM, ½ WATT 1%, R8
1	11K	A.B. MIL-R-11	RESISTOR, R9
2	22K	A.B. MIL R-11	RESISTOR, R10, R26
1	4.5K	TEPRO	RESISTOR, WW, ½ WATT 1%, R11
1	240Ω	A.B. MIL-R-11	RESISTOR, 1WATT, R13
2	680Ω	A.B. MIL R-11	RESISTOR, R14, R23

HAMILTON STANDARD PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 10 WATT
PARTS LIST NO. SK67819

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
1	62K	A.B. MIL-R-11	RESISTOR, R15
1	82Ω	A.B. MIL-R-11	RESISTOR, R16
1	33 K	A.B. MIL-R-11	RESISTOR, R17
2	4.3K	A.B. MIL-R-11	RESISTOR, R19, R22
1	10K	A.B. MIL-R-11	RESISTOR, R21
1	470Ω	A.B. MIL-R-11	RESISTOR, R 24
2	2K	A.B. MIL-R-11	RESISTOR, R25, R35
2	330Ω	A.B. MIL-R-11	RESISTOR, R27, R33
1	33Ω	A.B. MIL-R-11	RESISTOR, R28
1	510Ω	A.B. MIL-R-11	RESISTOR, 1 WATT, R29
1	47Ω	A.B. MIL-R-11	RESISTOR, R30
1	2.7K	A.B. MIL-R-11	RESISTOR, R31
1	0.51Ω	TEPRO	RESISTOR, WW, 5 WATT 5%, R32
1	390K	A.B. MIL-R-11	RESISTOR, R34
1	3.9K	MEPCO	RESISTOR, METAL FILM, ½ WATT 1%, R36
2	18X716796	HAMILTON STANDARD	CHOKE, FILTER, L1, L3
1	18X716794	HAMILTON STANDARD	CHOKE, L2
1	18X716719	HAMILTON STANDARD	TRANSFORMER, T1



NOTES
1. ALL RESISTORS ½ WATT CARBON COMPOSITION EXCEPT WHERE NOTED
2. ⏚ INDICATES SIGNAL GROUND
3. ⏚ INDICATES POWER GROUND
4. C1 IS TWO 52 µf CAPACITORS IN PARALLEL
5. C10 IS THREE 52 µf CAPACITORS IN PARALLEL
6. C11 IS TWO 52 µf CAPACITORS IN PARALLEL

SK67819

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ANGLES ±
EXCEPT FOR DRILL END FORMS, FILLET RADII
SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN TIR
MARK PART IDENTIFICATION: MIL-STD-130 PER HS333.
DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC
DC TO DC CONVERTER
BOOSTER 10 WATT

SIZE D | CODE IDENT NO. 73030 | SK67819

HAMILTON STANDARD
PARTS LIST

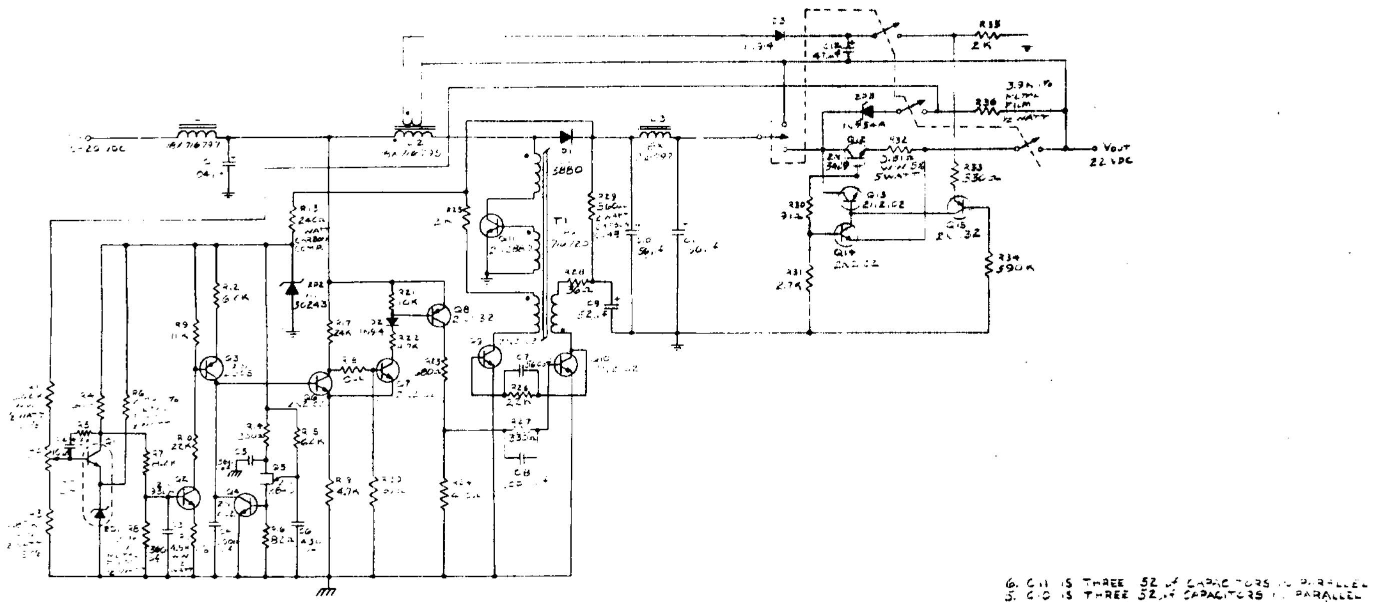
PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 25 WATT
PARTS LIST NO. SK67820

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
1	RA2A	G.E.	TRANSISTOR, REF. AMP., Q1, ZD1
1	2N930A	TRANSITRON	TRANSISTOR, Q2
1	2N2605	TRANSITRON	TRANSISTOR, Q3
7	2N2102	R.C.A.	TRANSISTOR, Q4, Q6, Q7, Q9, Q10, Q13, Q14
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q5
2	2N1132	FAIRCHILD	TRANSISTOR, Q8, Q15
1	2N2880	SOLITRON	TRANSISTOR, POWER, Q11
1	2N3429	WESTINGHOUSE	TRANSISTOR, POWER, Q12
1	1N3880	WESTINGHOUSE	DIODE, D1
2	1N914	TRANSITRON	DIODE, D2, D3
1	1N3024B	HOFFMAN	DIODE, ZENER, ZD2
1	1N754A	HOFFMAN	DIODE, ZENER, ZD3
9	52 µf	G.E. 29F352IG2	CAPACITOR, C1, C9, C10, C11
1	10 µf	T.I. SCM-4-653414	CAPACITOR, C2
1	360 pf	CD22A5T36JE	CAPACITOR, C3
2	.0011 µf	CD22A5D11	CAPACITOR, C4, C8
2	560 pf	CD22A3T56TE	CAPACITOR, C5, C7
1	430 pf	CD22A5T43JE	CAPACITOR, C6
1	47 µf	G.E. 69F121	CAPACITOR, C12
1	5.62 K	TEPRO	RESISTOR, WW, 1/2 WATT 5%, R1
1	2 K	BOURNS	RESISTOR, VARIABLE, WW, R2
1	2.87 K	TEPRO	RESISTOR, WW, 1/2 WATT 5%, R3
2	6.2 K	A.B. MIL-R-11	RESISTOR, R4, R12
1	3 K	A.B. MIL-R-11	RESISTOR, R5
2	2.7K	MEPCO	RESISTOR, METAL FILM 1/2 WATT 1%, R6, R8
1	8.2 K	A.B. MIL-R-11	RESISTOR, R7
1	11 K	A.B. MIL-R-11	RESISTOR, R9
2	22 K	A.B. MIL-R-11	RESISTOR, R10, R26
1	4.5 K	TEPRO	RESISTOR, WW, 1/2 WATT 1%, R11
1	240 Ω	A.B. MIL-R-11	RESISTOR, 1 WATT, R13
1	200 Ω	A.B. MIL-R-11	RESISTOR, R14
1	62 K	A.B. MIL-R-11	RESISTOR, R15
1	82 Ω	A.B. MIL-R-11	RESISTOR, R16

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 25 WATT
PARTS LIST NO. SK67820

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
1	24K	A.B. MIL-R-11	RESISTOR, R17
2	4.7K	A.B. MIL-R-11	RESISTOR, R19, R22
1	10K	A.B. MIL-R-11	RESISTOR, R21
1	680Ω	A.B. MIL-R-11	RESISTOR, R23
1	470Ω	A.B. MIL-R-11	RESISTOR, R24
2	2K	A.B. MIL-R-11	RESISTOR, R25, R35
2	330Ω	A.B. MIL-R-11	RESISTOR, R27, R33
1	36Ω	A.B. MIL-R-11	RESISTOR, R28
1	560Ω	A.B. MIL-R-11	RESISTOR, 2 WATT, R29
1	91Ω	A.B. MIL-R-11	RESISTOR, R30
1	2.7K	A.B. MIL-R-11	RESISTOR, R31
1	0.51Ω	TEPRO	RESISTOR, WW, 5WATT 5%, R32
1	390K	A.B. MIL-R-11	RESISTOR, R34
1	3.9K	MEPCO	RESISTOR, METAL FILM, ½WATT, 1%, R36
2	18X716797	HAMILTON STANDARD	CHOKE, FILTER, L1, L3
1	18X716795	HAMILTON STANDARD	CHOKE, L2
1	18X716720	HAMILTON STANDARD	TRANSFORMER, T1



NOTES
1. ALL RESISTORS ½ WATT CARBON COMPOSITION EXCEPT WHERE NOTED
2. ⏚ INDICATES SIGNAL GROUND
3. ⏚ INDICATES POWER GROUND
4. C1 IS TWO 52μf CAPACITORS IN PARALLEL
5. C10 IS THREE 52μf CAPACITORS IN PARALLEL
6. C11 IS THREE 52μf CAPACITORS IN PARALLEL

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC
DC TO DC CONVERTER
BOOSTER 25 WATT

SIZE D | 73030 | SK67820

SK67820

HAMILTON STANDARD PARTS LIST

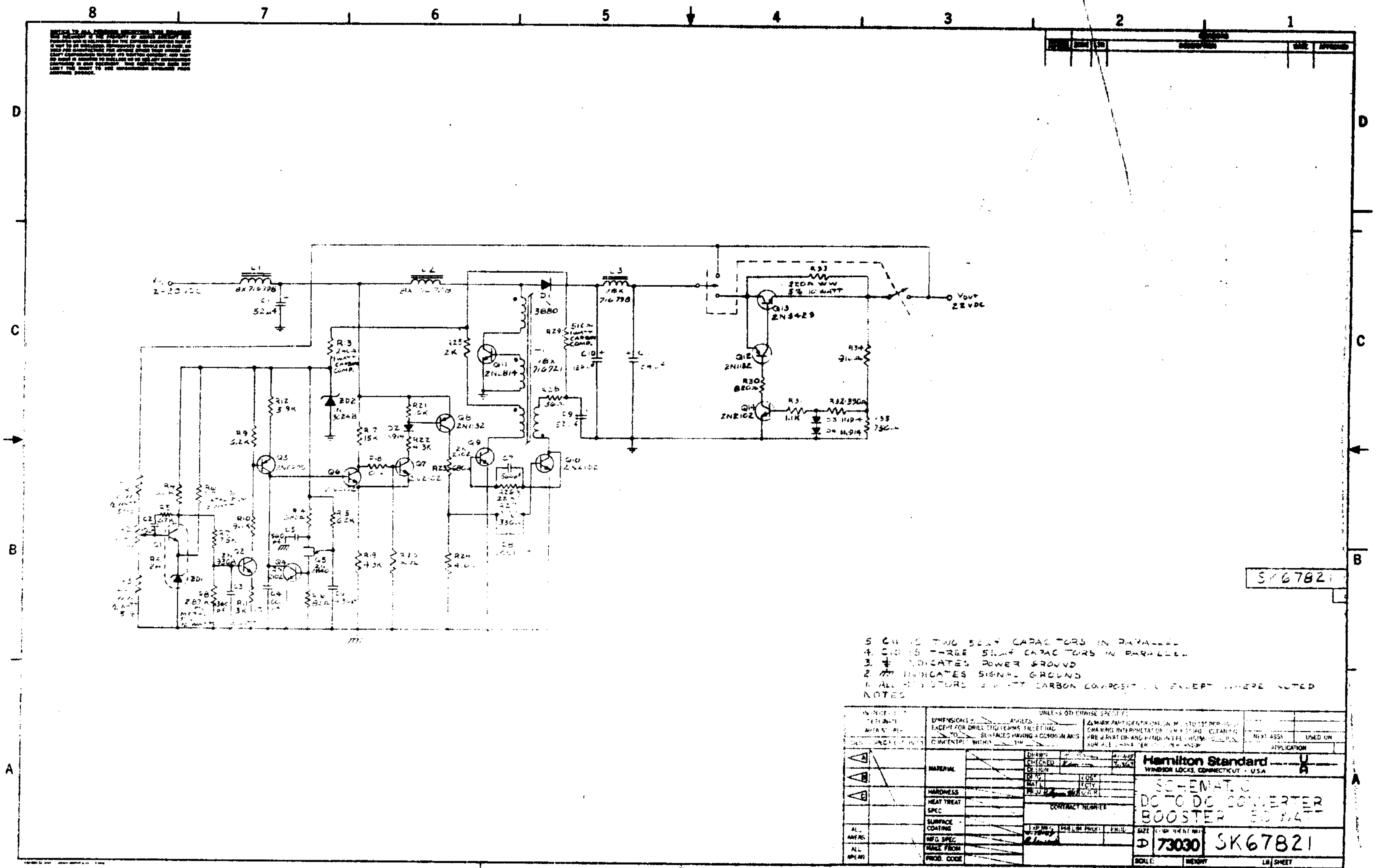
PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 50 WATT
PARTS LIST NO. SK67821

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
1	RA2A	G.E.	TRANSISTOR, REF. AMP, Q1, ZD1
1	2N930A	TRANSITRON	TRANSISTOR, Q2
1	2N2605	TRANSITRON	TRANSISTOR, Q3
6	2N2102	R.C.A.	TRANSISTOR, Q4, Q6, Q7, Q9, Q10, Q14
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q5
2	2N1132	FAIRCHILD	TRANSISTOR, Q8, Q12
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q11
1	2N3429	WESTINGHOUSE	TRANSISTOR, POWER, Q13
1	IN3880	WESTINGHOUSE	DIODE, D1
3	IN914	TRANSITRON	DIODE, D2, D3, D4
1	IN3024B	HOFFMAN	DIODE, ZENER, ZD2
7	52 µf	G.E. 29F352162	CAPACITOR, C1, C9, C10, C11
1	10 µf	T.I. SKM-4-653H14	CAPACITOR, C2
1	360 pf	CD 22A5T36JE	CAPACITOR, C3
2	.0011 µf	CD 22A5D11	CAPACITOR, C4, C8
2	560 pf	CD 22A3T56JE	CAPACITOR, C5, C7
1	430 pf	CD 22A5TA3JE	CAPACITOR, C6
1	9K	TEPRO	RESISTOR, WW, ½ WATT, 5%, R1
1	2K	BOURNS	RESISTOR, VARIABLE, WW, R2
1	4K	TEPRO	RESISTOR, WW, ½ WATT, 5%, R3
2	6.2K	A.B. MIL-R-11	RESISTOR, R4, R9
1	2.7K	A.B. MIL-R-11	RESISTOR, R5
1	2.7K	MEPCO	RESISTOR, METAL FILM, ½ WATT 1%, R6
1	7.5K	A.B. MIL-R-11	RESISTOR, R7
1	2.87K	MEPCO	RESISTOR, METAL FILM, ½ WATT 1%, R8
1	9.1K	A.B. MIL-R-11	RESISTOR, R10
1	3K	TEPRO	RESISTOR, WW, ½ WATT 1%, R11
1	3.9K	A.B. MIL-R-11	RESISTOR, R12
1	240Ω	A.B. MIL-R-11	RESISTOR, 1 WATT, R13
2	680Ω	A.B. MIL-R-11	RESISTOR, R14, R23
1	62K	A.B. MIL-R-11	RESISTOR, R15
1	82Ω	A.B. MIL-R-11	RESISTOR, R16
1	15K	A.B. MIL-R-11	RESISTOR, R17

HAMILTON STANDARD PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 50 WATT
PARTS LIST NO. SK67827

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	4.3K	A.B. MIL-R-11	RESISTOR, R19, R22
1	10K	A.B. MIL-R-11	RESISTOR, R21
1	470Ω	A.B. MIL-R-11	RESISTOR, R24
1	2K	A.B. MIL-R-11	RESISTOR, R25
1	22K	A.B. MIL-R-11	RESISTOR, R26
1	330Ω	A.B. MIL-R-11	RESISTOR, R27
1	36Ω	A.B. MIL-R-11	RESISTOR, R28
1	510Ω	A.B. MIL-R-11	RESISTOR, 1 WATT, R29
1	820Ω	A.B. MIL-R-11	RESISTOR, R30
1	1.1K	A.B. MIL-R-11	RESISTOR, R31
1	390Ω	A.B. MIL-R-11	RESISTOR, R32
1	220Ω	TEPRO	RESISTOR, WW, 10 WATT 5%, R33
1	910Ω	A.B. MIL-R-11	RESISTOR, R34
1	750Ω	A.B. MIL-R-11	RESISTOR, R35
2	18X716798	HAMILTON STANDARD	CHOKE, FILTER, L1, L3
1	18X716728	HAMILTON STANDARD	CHOKE, L2
1	18X716721	HAMILTON STANDARD	TRANSFORMER, T1


NOTES
1. ALL RESISTORS 1/4 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
2. INDICATES SIGNAL GROUND
3. INDICATES POWER GROUND
4. C10 IS THREE 51μf CAPACITORS IN PARALLEL
5. C11 IS TWO 52μf CAPACITORS IN PARALLEL
Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • USA
SCHEMATIC
DC TO DC CONVERTER
BOOSTER 50 WATT
D 73030 SK67821
VOUT 28 VDC

HAMILTON STANDARD
PARTS LIST

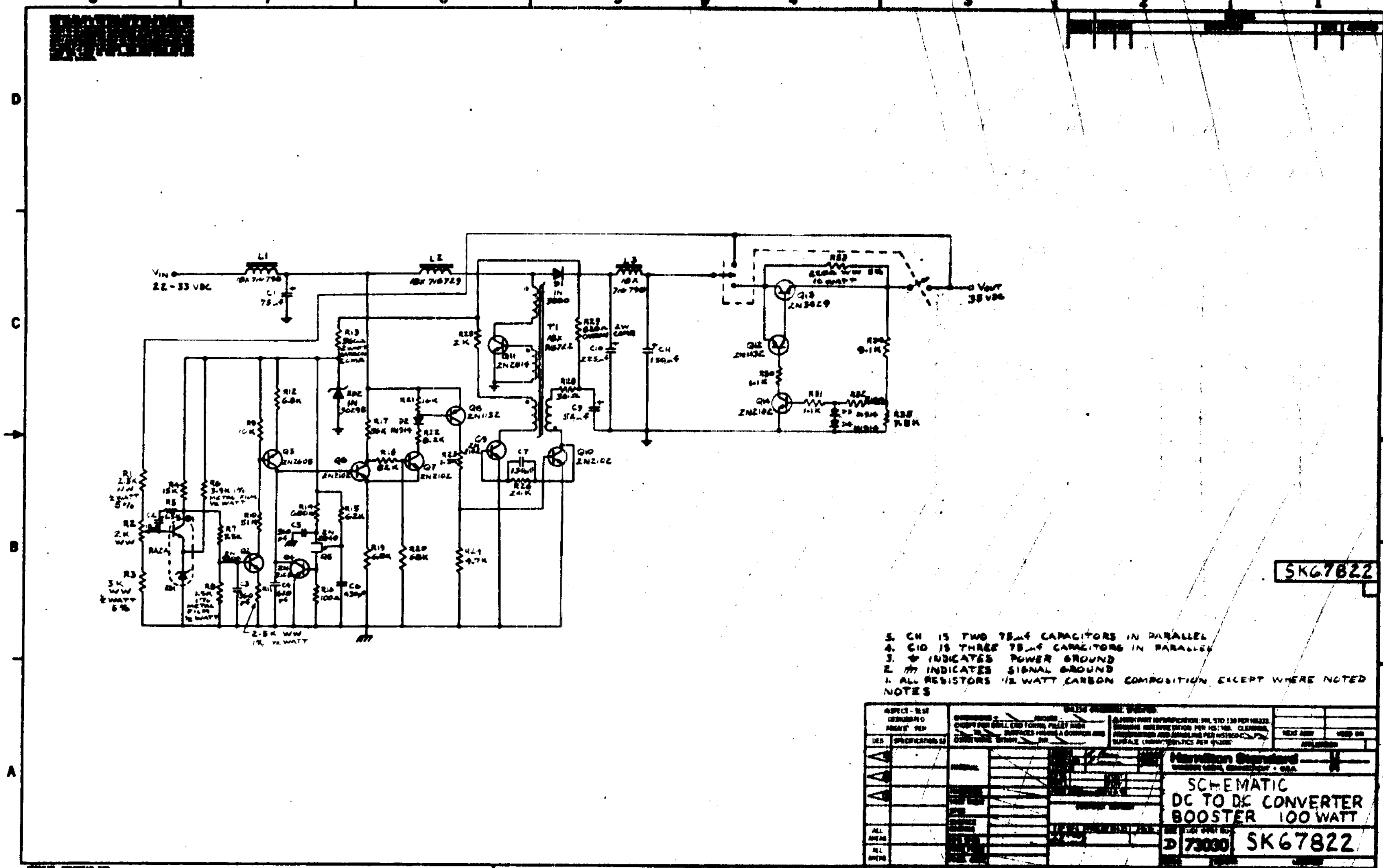
PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 100 WATT
PARTS LIST NO. SK67822

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
1	RA2A	G.E.	TRANSISTOR, REF. AMP., Q1, ZD1
1	2N930A	TRANSITRON	TRANSISTOR, Q2
1	2N2605	TRANSITRON	TRANSISTOR, Q3
6	2N2102	R.C.A.	TRANSISTOR, Q4, Q6, Q7, Q9, Q10, Q14
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q5
2	2N1132	FAIRCHILD	TRANSISTOR, Q8, Q12
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q11
1	2N3429	WESTINGHOUSE	TRANSISTOR, POWER, Q13
1	1N3880	WESTINGHOUSE	DIODE, D1
3	1N914	TRANSITRON	DIODE, D2, D3, D4
1	1N3029B	MOTOROLA	DIODE, ZENER, ZD2
6	75 µf	G.E. 29F3532	CAPACITOR, C1, C10, C11
1	10 µf	T.I. SCM-4-6534114	CAPACITOR, C2
1	360 pf	C.D. 22A5T36JE	CAPACITOR, C3
1	620 pf	C.D. 22A3T62JE	CAPACITOR, C4
1	560 pf	C.D. 22A5T56JE	CAPACITOR, C5
1	430 pf	C.D. 22A5T43JE	CAPACITOR, C6
1	130 pf	C.D. 22A5T13JE	CAPACITOR, C7
1	52 µf	G.E. 29F3521B2	CAPACITOR, C9
1	2.5K	TEPRO	RESISTOR, WW, ½ WATT, 5%, R1
1	2K	BOURNS	RESISTOR, VARIABLE, WW, R2
1	3K	TEPRO	RESISTOR, WW, ½ WATT, 5%, R3
1	15K	A.B. MIL-R-11	RESISTOR, R4
2	1.5K	A.B. MIL-R-11	RESISTOR, R5, R23
1	3.9K	MEPCO	RESISTOR, METAL FILM, ½ WATT, 1%, R6
2	7.5K	A.B. MIL-R-11	RESISTOR, R7, R35
1	1.5K	MEPCO	RESISTOR, METAL FILM, ½ WATT, 1%, R8
1	10K	A.B. MIL-R-11	RESISTOR, R9
1	51K	A.B. MIL-R-11	RESISTOR, R10
1	2.5K	TEPRO	RESISTOR, WW, ½ WATT, 1%, R11
2	6.8K	A.B. MIL-R-11	RESISTOR, R12, R19
1	560Ω	A.B. MIL-R-11	RESISTOR, 2 WATT, R13
1	680Ω	A.B. MIL-R-11	RESISTOR, R14

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, BOOSTER, 100 WATT
PARTS LIST NO. SK67822

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
1	62K	A.B. MIL-R-11	RESISTOR, R15
1	100Ω	A.B. MIL-R-11	RESISTOR, R16
1	56K	A.B. MIL-R-11	RESISTOR, R17
1	82K	A.B. MIL-R-11	RESISTOR, R18
1	68K	A.B. MIL-R-11	RESISTOR, R20
1	16K	A.B. MIL-R-11	RESISTOR, R21
1	8.2K	A.B. MIL-R-11	RESISTOR, R22
1	4.7K	A.B. MIL-R-11	RESISTOR, R24
1	2K	A.B. MIL-R-11	RESISTOR, R25
1	24K	A.B. MIL-R-11	RESISTOR, R26
1	36Ω	A.B. MIL-R-11	RESISTOR, R28
1	620Ω	A.B. MIL-R-11	RESISTOR, 2WATT, R29
2	1.1K	AB. MIL-R-11	RESISTOR, R30, R31
1	510Ω	A.B. MIL-R-11	RESISTOR, R32
1	220Ω	TEPRO	RESISTOR, WW, 10WATT, 5% R33
1	9.1K	A.B. MIL-R-11	RESISTOR, R34
2	18X716798	HAMILTON STANDARD	CHOKE, FILTER, L1, L3
1	18X716729	HAMILTON STANDARD	CHOKE, L2
1	18X716722	HAMILTON STANDARD	TRANSFORMER, T1


VIN 22 - 33 VDC
VOUT 38 VDC
SK67822
5. C11 IS TWO 75µf CAPACITORS IN PARALLEL
4. C10 IS THREE 75µf CAPACITORS IN PARALLEL
3. INDICATES POWER GROUND
2. INDICATES SIGNAL GROUND
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
NOTES
Hamilton Standard
SCHEMATIC
DC TO DC CONVERTER
BOOSTER 100 WATT
D 73030 SK67822

PHASE II

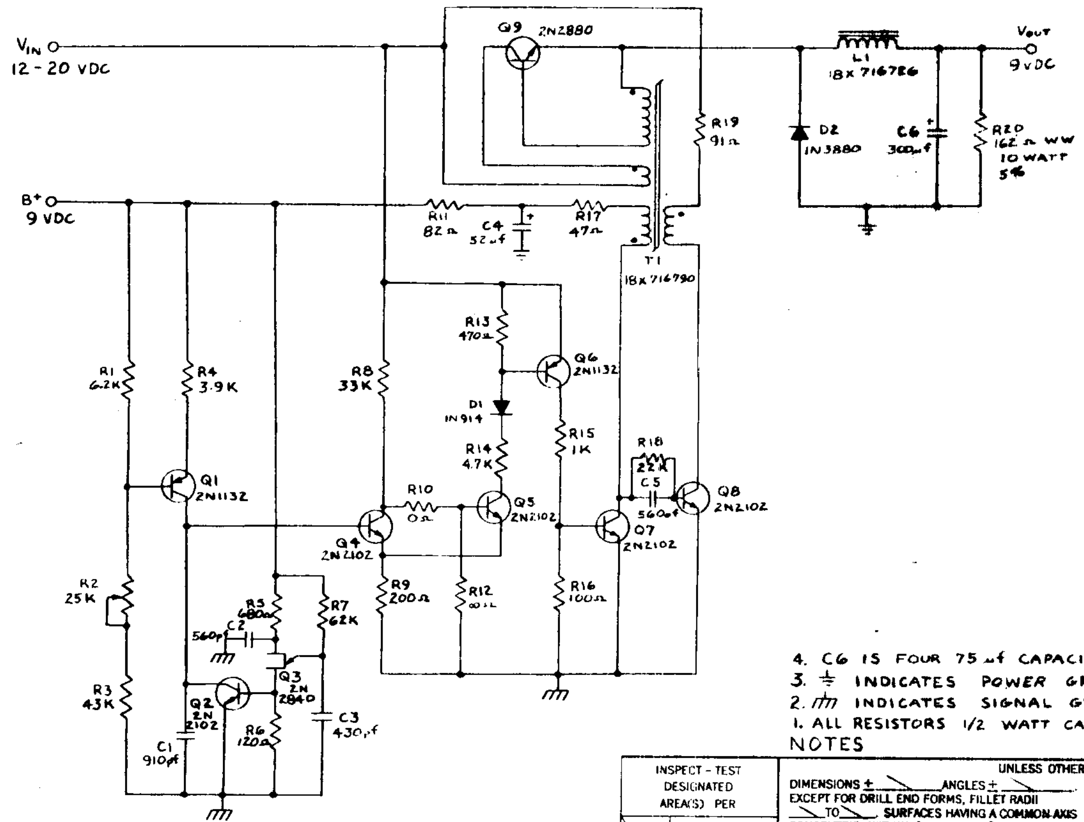
CHOPPERS

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, CHOPPER, 10 WATT
PARTS LIST NO. SK67815

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6
5	2N2102	R.C.A.	TRANSISTOR, Q2, Q4, Q5, Q7, Q8
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q3
1	2N2880	SOLITRON	TRANSISTOR, POWER, Q9
1	910 pf	CD22A5T91JE	CAPACITOR, C1
2	560 pf	CD22A3T56JE	CAPACITOR, C2, C5
1	430 pf	CD 22A5T43JE	CAPACITOR, C3
1	52 μf	G.E. 29F352162	CAPACITOR, C4
4	75 μf	G.E. 29F3632	CAPACITOR, C6
1	1N914	TRANSITRON	DIODE, D1
1	1N3880	WESTINGHOUSE	DIODE, D2
1	6.2 K	A-B MIL-R-11	RESISTOR, R1
1	25 K	A.B. MIL-R-11	RESISTOR, VARIABLE, R2
1	43 K	A.B. MIL-R-11	RESISTOR, R3
1	3.9 K	A.B. MIL-R-11	RESISTOR, R4
1	680 Ω	A.B. MIL-R-11	RESISTOR, R5
1	120 Ω	A.B. MIL-R-11	RESISTOR, R6
1	62 K	A.B. MIL-R-11	RESISTOR, R7
1	33 K	A.B. MIL-R-11	RESISTOR, R8
1	200 Ω	A.B. MIL-R-11	RESISTOR, R9
1	82 Ω	A.B. MIL-R-11	RESISTOR, R11
1	470 Ω	A.B. MIL-R-11	RESISTOR, R13
1	4.7 K	A.B. MIL-R-11	RESISTOR, R14
1	1 K	A.B. MIL-R-11	RESISTOR, R15
1	100 Ω	A.B. MIL-R-11	RESISTOR, R16
1	47 Ω	A.B. MIL-R-11	RESISTOR, R17
1	22 K	A.B. MIL-R-11	RESISTOR, R18
1	91 Ω	A.B. MIL-R-11	RESISTOR, R19
1	162 Ω	TEPRO	RESISTOR, WW, 10 WATT ±5%, R20
1	18X716726	HAMILTON STANDARD	CHOKE, L1
1	18X716790	HAMILTON STANDARD	TRANSFORMER, T1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



SK67815

NOTES
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
2. ⊥ INDICATES SIGNAL GROUND
3. ⏚ INDICATES POWER GROUND
4. C6 IS FOUR 75 μf CAPACITORS IN PARALLEL

INSPECT - TEST DESIGNATED AREA(S) PER	
DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ANGLES ±
EXCEPT FOR DRILL END FORMS, FILLET RADII TO
SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN TIR

△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333.
DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C P
SURFACE CHARACTERISTICS PER HS1082.

NEXT ASSY	USED ON
APPLICATION	

MATERIAL	
HARDNESS	
HEAT TREAT SPEC	
SURFACE COATING	
MFG SPEC	
MAKE FROM	
PROD. CODE	

DRAWN		
CHECKED		
DESIGN		
DFTG	COST	
MAT'L	FCTY	
PROJ	D & R	

CONTRACT NUMBER

EXP MFG	PRELIM PROD.	PROD.

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT • U.S.A.

SCHEMATIC
DC TO DC CONVERTER
CHOPPER, 10 WATT

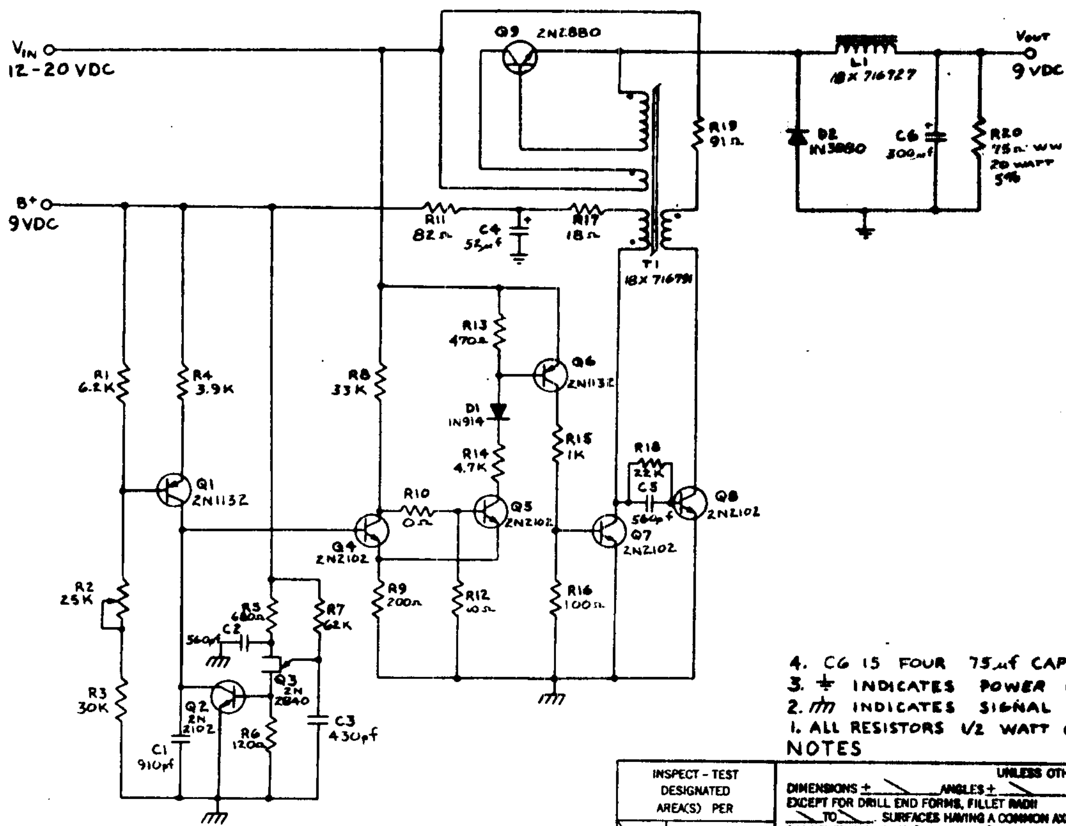
SIZE	CODE IDENT NO.	
C	73030	SK67815

SCALE:	WEIGHT:	LB	SHEET

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, CHOPPER, 25 WATT
PARTS LIST NO. SK67816

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6
5	2N2102	R.C.A.	TRANSISTOR, Q2, Q4, Q5, Q7, Q8
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q3
1	2N2880	SOLITRON	TRANSISTOR, POWER, Q9
1	1N914	TRANSITRON	DIODE, D1
1	1N3880	WESTINGHOUSE	DIODE, D2
1	910 pf	C.D. 22A5T91JE	CAPACITOR, C1
2	560 pf	C.D. 22A3T56JE	CAPACITOR, C2, C5
1	430 pf	C.D. 22A5T43JE	CAPACITOR, C3
1	52 μf	G.E. 29F3521Q	CAPACITOR, C4
4	75 μf	G.E. 29F3632	CAPACITOR, C6
1	6.2 K	A.B. MIL-R-11	RESISTOR, R1
1	25 K	A.B. MIL-R-11	RESISTOR, VARIABLE, R2
1	30K	A.B. MIL-R-11	RESISTOR, R3
1	3.9K	A.B. MIL-R-11	RESISTOR, R4
1	680Ω	A.B. MIL-R-11	RESISTOR, R5
1	120Ω	A.B. MIL-R-11	RESISTOR, R6
1	62 K	A.B. MIL-R-11	RESISTOR, R7
1	33 K	A.B. MIL-R-11	RESISTOR, R8
1	200Ω	A.B. MIL-R-11	RESISTOR, R9
1	82Ω	A.B. MIL-R-11	RESISTOR, R11
1	470Ω	A.B. MIL-R-11	RESISTOR, R13
1	4.9K	A.B. MIL-R-11	RESISTOR, R14
1	1K	A.B. MIL-R-11	RESISTOR, R15
1	100Ω	A.B. MIL-R-11	RESISTOR, R16
1	.8Ω	A.B. MIL-R-11	RESISTOR, R17
1	22 K	A.B. MIL-R-11	RESISTOR, R18
1	91Ω	A.B. MIL-R-11	RESISTOR, R19
1	75Ω	TEPRO	RESISTOR, WW, 20 WATT, 5%, R20
1	18X716727	HAMILTON STANDARD	CHOKE, L1
1	18X716791	HAMILTON STANDARD	TRANSFORMER, T1



4. C6 IS FOUR 75μf CAPACITORS IN PARALLEL
3. ⏚ INDICATES POWER GROUND
2. ⫨ INDICATES SIGNAL GROUND
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED

NOTES

INSPECT - TEST DESIGNATED AREA(S) PER	
DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___. SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR.

△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1950-C. SURFACE CHARACTERISTICS PER HS1082.

MATERIAL
HARDNESS
HEAT TREAT SPEC
SURFACE COATING
MFG SPEC
MAKE FROM
PROD. CODE

DRAWN
CHECKED
DESIGN
OPTG
MAT'L
PROJ
COST
TCHY
RQD & R

CONTRACT NUMBER

EXP'MTL | PRELIM PROD. | PROD.

NEXT ASSY | USED ON
APPLICATION

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT · U.S.A.

SCHEMATIC
DC TO DC CONVERTER
CHOPPER 25 WATT

SIZE	CODE IDENT NO.	
C	73030	SK67816

SCALE: | WEIGHT: | LB | SHEET

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

SK67816

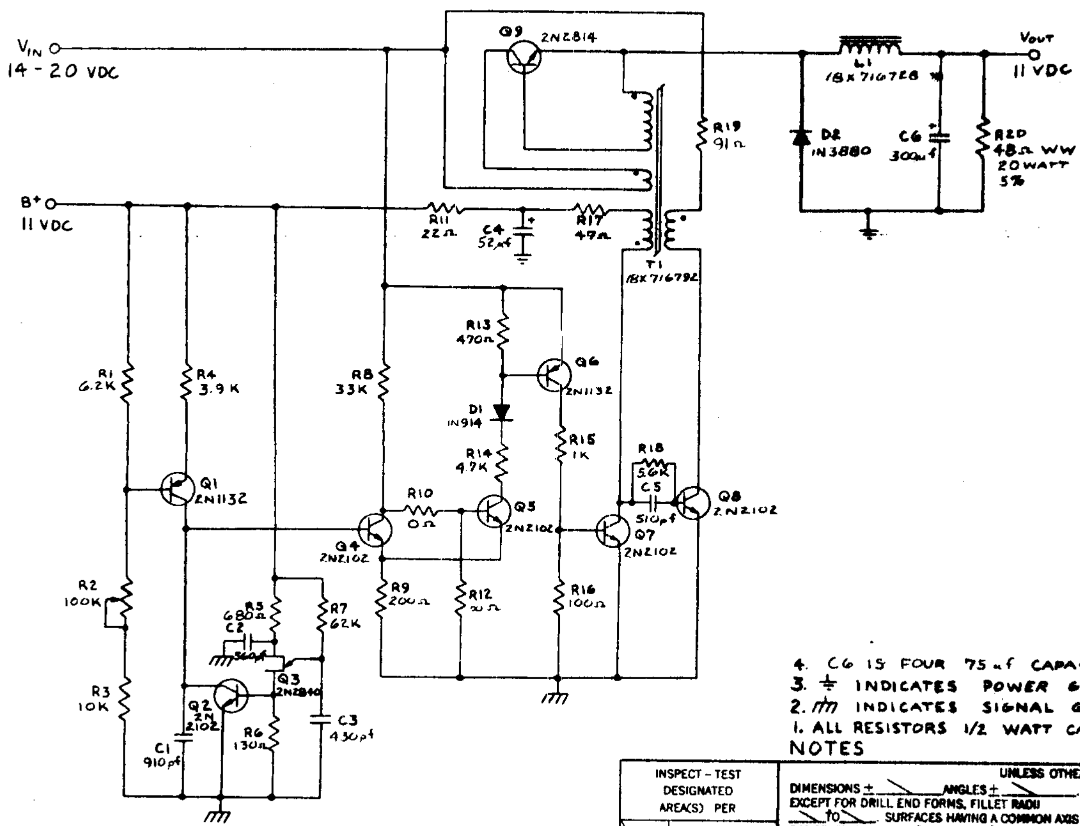
HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, CHOPPER, 50 WATT
PARTS LIST NO. SK67817

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6
5	2N2102	R.C.A.	TRANSISTOR, Q2, Q4, Q5, Q7, Q8
1	2N2840	G.E.	TRANSISTOR, UNIJUNCTION, Q3
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q9
1	1N914	TRANSITRON	DIODE, D1
1	1N3880	WESTINGHOUSE	DIODE, D2
1	910 pf	CD 22A5T91JE	CAPACITOR, C1
1	560 pf	CD 22A3T56JE	CAPACITOR, C2
1	430 pf	CD 22A5T43JE	CAPACITOR, C3
1	52 μf	G.E. 29F352162	CAPACITOR, C4
1	510 pf	C.D. 22A3T51JE	CAPACITOR, C5
4	75 μf	G.E. 29F3632	CAPACITOR, C6
1	6.2K	A.B. MIL-R-11	RESISTOR, R1
1	100K	A.B. MIL-R-11	RESISTOR, VARIABLE, R2
1	10K	A.B. MIL-R-11	RESISTOR, R3
1	3.9[illegible]	A.B. MIL-R-11	RESISTOR, R4
1	[illegible]	A.B. MIL-R-11	RESISTOR, R5
1	130 Ω	A.B. MIL-R-11	RESISTOR, R6
1	62K	A.B. MIL-R-11	RESISTOR, R7
1	33K	A.B. MIL-R-11	RESISTOR, R8
1	200 Ω	A.B. MIL-R-11	RESISTOR, R9
1	22 Ω	A.B. MIL-R-11	RESISTOR, R11
1	470 Ω	A.B. MIL-R-11	RESISTOR, R13
1	4.7K	A.B. MIL-R-11	RESISTOR, R14
1	1K	A.B. MIL-R-11	RESISTOR, R15
1	100 Ω	A.B. MIL-R-11	RESISTOR, R16
1	47 Ω	A.B. MIL-R-11	RESISTOR, R17
1	5.6K	A.B. MIL-R-11	RESISTOR, R18
1	91 Ω	A.B. MIL-R-11	RESISTOR, R19
1	48 Ω	TEPRO	RESISTOR, WW, 20 WATT, 5%, R20
1	18X716728	HAMILTON STANDARD	CHOKE, L1
1	18X716792	HAMILTON STANDARD	TRANSFORMER, T1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

SK67817



4. C6 IS FOUR 75µf CAPACITORS IN PARALLEL
3. ⏚ INDICATES POWER GROUND
2. ⫫ INDICATES SIGNAL GROUND
1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED

NOTES

INSPECT - TEST DESIGNATED AREA(S) PER

DES	SPECIFICATION(S)
A	
B	
C	
ALL AREAS	
ALL AREAS	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ± ___ ANGLES ± ___
EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___ SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR ___

△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C ___ P ___. SURFACE CHARACTERISTICS PER HS1082.

NEXT ASSY	USED ON
APPLICATION	

MATERIAL
HARDNESS
HEAT TREAT SPEC
SURFACE COATING
MFG SPEC
MAKE FROM
PROD. CODE

DRAWN R. [illegible] 9/1/67
CHECKED [illegible]
DESIGN
DFTG
MAT'L
PROJ
COST
FCTY
Q & R
CONTRACT NUMBER
EXP MFG 9-15-67
PRELIM PROD.
PROD.

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT · U.S.A.

SCHEMATIC DC TO DC CONVERTER CHOPPER 50 WATT

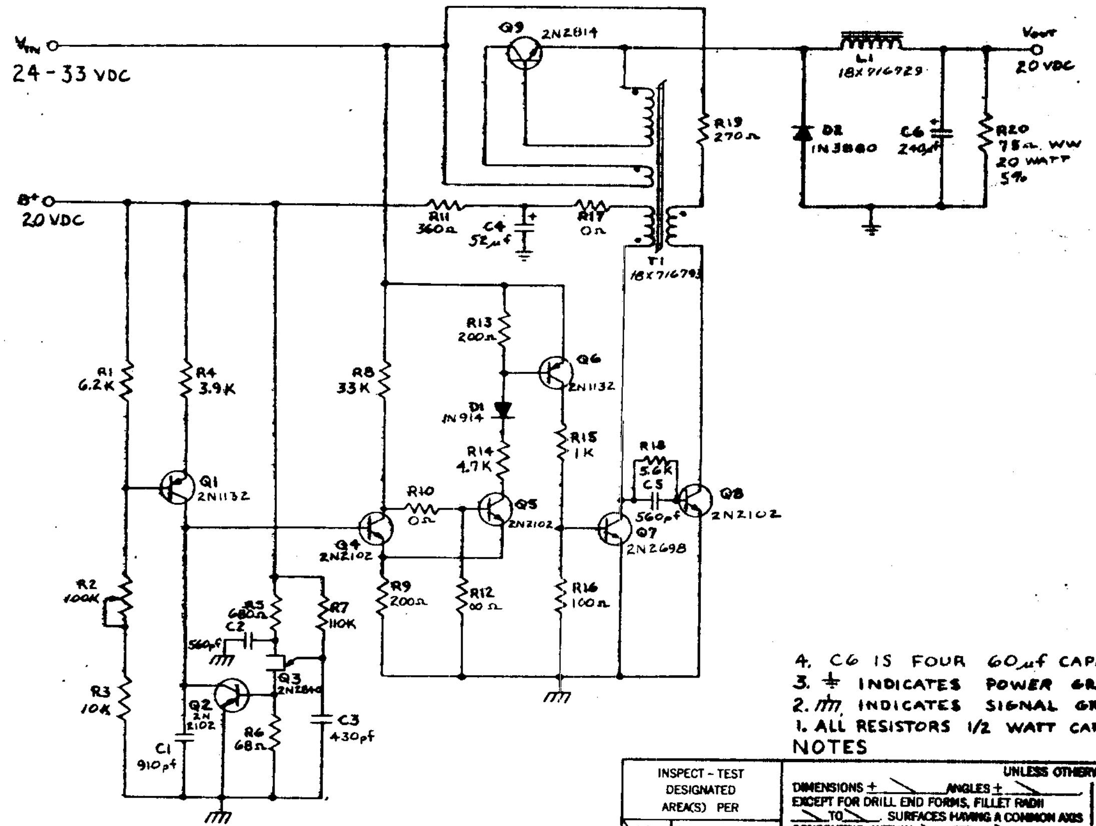
SIZE	CODE IDENT NO.	
C	73030	SK67817

SCALE: WEIGHT: LB SHEET

HAMILTON STANDARD
PARTS LIST

PARTS LIST FOR DC TO DC CONVERTER, CHOPPER, 100 WATT
PARTS LIST NO. SK67818

REQUIRED	PART IDENTIFICATION	VENDOR	DESCRIPTION
2	2N1132	FAIRCHILD	TRANSISTOR, Q1, Q6
4	2N2102	R.C.A.	TRANSISTOR, Q2, Q4, Q5 Q8
1	2N2840	G.E.	TRANSISTOR, Q3
1	2N2698		TRANSISTOR, Q7
1	2N2814	SOLITRON	TRANSISTOR, POWER, Q9
1	IN914	TRANSITRON	DIODE, D1
1	IN3880	WESTINGHOUSE	DIODE, D2
1	910 pf	CD22A5T91JE	CAPACITOR, C1
2	560 pf	CD22A3T56JE	CAPACITOR, C2, C5
1	430 pf	CD22A5T43JE	CAPACITOR C3
1	52 µf	G.E. 29F352162	CAPACITOR, C4
4	60 µf	G.E. 69F36066	CAPACITOR, C6
1	6.2K	A.B. MIL-R 11	RESISTOR, R1
1	100K	A.B. MIL-R-11	RESISTOR, VARIABLE, R2
1	10K	A.B. MIL-R-11	RESISTOR, R3
1	3.9K	A.B. MIL-R-11	RESISTOR, R4
1	680Ω	A.B. MIL-R-11	RESISTOR, R5
1	68Ω	A.B. MIL-R-11	RESISTOR, R6
1	110K	A.B. MIL-R-11	RESISTOR, R7
1	33K	A.B. MIL-R-11	RESISTOR, R8
2	200Ω	A.B. MIL-R-11	RESISTOR, R9, R13
1	360Ω	A.B. MIL-R-11	RESISTOR R11
1	4.7K	A.B. MIL-R-11	RESISTOR, R14
1	1K	A.B. MIL-R-11	RESISTOR, R15
1	100Ω	A.B. MIL-R-11	RESISTOR, R16
1	5.6K	A.B. MIL-R-11	RESISTOR, R18
1	270Ω	A.B. MIL-R-11	RESISTOR, R19
1	75Ω	TEPRO	RESISTOR, WW, 20 WATT, 5%, R20
1	18X716729	HAMILTON STANDARD	CHOKE, L1
1	18X716793	HAMILTON STANDARD	TRANSFORMER, T1



SK67818

NOTES

1. ALL RESISTORS 1/2 WATT CARBON COMPOSITION EXCEPT WHERE NOTED
2. ⫻ INDICATES SIGNAL GROUND
3. ⏚ INDICATES POWER GROUND
4. C6 IS FOUR 60μf CAPACITORS IN PARALLEL

INSPECT - TEST DESIGNATED AREA(S) PER	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ± ___ ANGLES ± ___ EXCEPT FOR DRILL END FORMS, FILLET RADII ___ TO ___ SURFACES HAVING A COMMON AXIS CONCENTRIC WITHIN ___ TIR ___	△ MARK PART IDENTIFICATION: MIL-STD-130 PER HS333. DRAWING INTERPRETATION PER HS1360. CLEANING, PRESERVATION AND HANDLING PER HS1550-C ___ P ___ SURFACE CHARACTERISTICS PER HS1082.	NEXT ASSY / USED ON / APPLICATION
DES / SPECIFICATION(S)	MATERIAL / HARDNESS / HEAT TREAT SPEC / SURFACE COATING / MFG SPEC / MAKE FROM / PROD. CODE	DRAWN 4/13/67 / CHECKED / DESIGN / DFTG / MAT'L / PROJ / COST / FCTY / Q & R / CONTRACT NUMBER / EXP MFG / PRELIM PROD. / PROD.	Hamilton Standard — WINDSOR LOCKS, CONNECTICUT · U.S.A.
A / B / C / ALL AREAS / ALL AREAS			SCHEMATIC DC TO DC CONVERTER CHOPPER 100 WATT
			SIZE C / CODE IDENT NO. 73030 / SK67818 / SCALE / WEIGHT: LB / SHEET

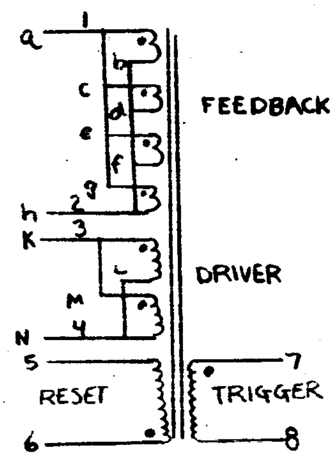
PHASE II

MAGNETICS DRAWINGS

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/07

P/N HS 716190 **TYPE:** 10W DRIVER-CHOPPER **USED ON:** NASA [illegible]

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	32	6'	100	7-8	.96 ±20%
5-6	597507	32	4'	32	5-6	.64 ±20%
K-L	597507	32	4'	32	3-4	.32 ±20%
M-N	597507	32	4'	32	3-4	.32 ±20%
a-b	597507	28	1'	2	1-2	.015 ±20%
c-d	597507	28	1'	2	1-2	.015 ±20%
e-f	597507	28	1'	2	1-2	.015 ±20%
g-h	597507	28	1'	2	1-2	.015 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN ABOVE - SPREAD WINDINGS OVER 360° OF CORE

INSULATION NONE

CORE 1180-250-42, ARNOLD ENG., MOLYPERMALLOY TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS - MIN. LENGTH [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER - Dimensions: Length **Width** **Height** **Volume** .0491 CU. IN. **Weight** .0094 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NO LOAD, WITH 0.5VRMS APPLIED TO TERMINALS 3-4, MEASURE .0312 VRMS 1-2, 0.5 VRMS 5-6, 1.57 VRMS 7-8

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS TAG LEADS WITH TERMINAL NO.S

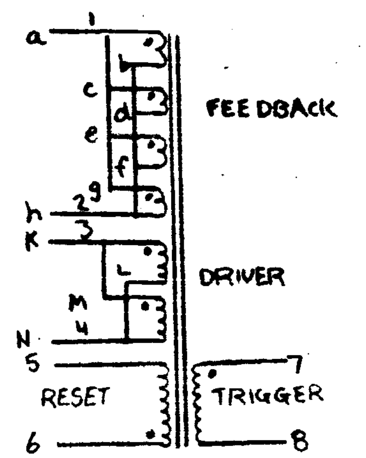
Engineer R. S[illegible] **Date:** 4/[illegible]

Approval **Date:**

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/67

P/N 1H: 716791 TYPE: 25W DRIVER CHOPPER USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	32	6'	100	7-8	.96 ±20%
5-6	597507	31	4'	32	5-6	.52 ±20%
K-L	597507	31	4'	32	3-4	.26 ±20%
M-N	597507	31	4'	32	3-4	.26 ±20%
a-b	597507	24	1'	2	1-2	.006 ±20%
c-d	597507	24	1'	2	1-2	.006 ±20%
e-f	597507	24	1'	2	1-2	.006 ±20%
g-h	597507	24	1'	2	1-2	.006 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN ABOVE - SPREAD WINDINGS OVER 360° OF CORE

INSULATION NONE

CORE 118D-250-42, ARNOLD ENG., MOLYPERMALLOY TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS, MIN. LENGTH [illegible]"

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER - Dimensions: Length Width Height Volume .0491 in cu Weight .0094 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NO LOAD, WITH 0.5VRMS APPLIED TO TERMINALS 3-4, MEASURE .03[illegible]VRMS 1-2, 0.5VRMS 5-6, 1.57VRMS 7-8

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS TAG LEADS WITH TERMINAL NO.S

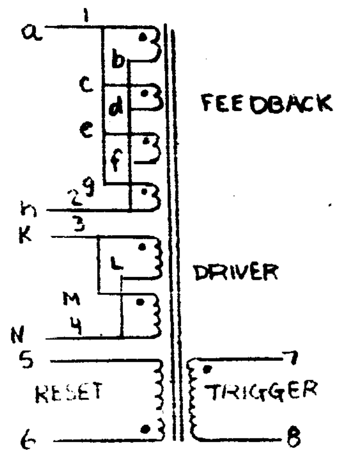
Engineer [illegible] Date: 4/8/66

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/67

P/N 18x 716792 TYPE: 50W. DRIVER-CHOPPER USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	31	6'	100	7-8	.79 ±20%
5-6	597507	30	5'	60	5-6	.52 ±20%
K-L	597507	30	5'	70	3-4	.26 ±20%
M-N	597507	30	5'	70	3-4	.26 ±20%
a-b	597507	23	1'	2	1-2	.005 ±20%
c-d	597507	23	1'	2	1-2	.005 ±20%
e-f	597507	23	1'	2	1-2	.005 ±20%
g-h	597507	23	1'	2	1-2	.005 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN ABOVE. SPREAD WINDINGS OVER 360° OF THE CORE

INSULATION NONE

CORE 118D-250-42, ARNOLD ENG., MOLYPERMALLOY TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. [illegible] LEADS - MIN. LENGTH [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER - Dimensions: Length Width Height Volume .0491 in cu Weight .0094 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

NO LOAD, WITH 0.5VRMS APPLIED TO TERMINALS 3-4, MEASURE .175VRMS 1-2,
VOLTAGE 0.4VRMS [illegible] AND 0.72VRMS 7-8

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

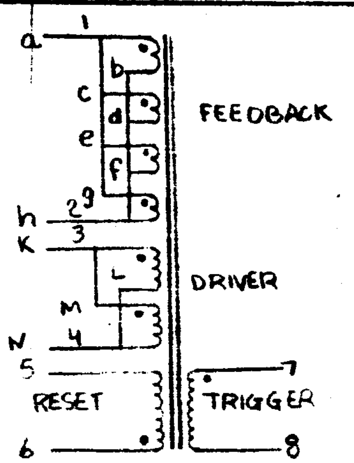
REMARKS TAG LEADS WITH TERMINAL NO'S

Engineer R Seaver Date: 4/6/67
Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/67

P/N 18x 716793 TYPE: 100W DRIVER-CHOPPER USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
7-8	597507	31	6'	100	7-8	.79 ±20
5-6	597507	28	4'	30	5-6	.26 ±20
K-L	597507	30	4'	40	3-4	.20 ±
M-N	597507	30	4'	40	3-4	.20 ±
a-b	597507	23	1'	2	1-2	.005 ±
c-d	597507	23	1'	2	1-2	.005 ±
e-f	597507	23	1'	2	1-2	.005 ±
g-h	597507	23	1'	2	1-2	.005 ±
						±
						±
						±
						±
						±
						±
						±
						±
						±

MANUFACTURING NOTES

WINDING WIND IN SEQUENCE SHOWN ABOVE - SPREAD WINDINGS OVER 360° OF THE CORE

INSULATION NONE

CORE 1180-[illegible]-42, ARNOLD ENG., MOLYPERMALLOY TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume .0491 in cu Weight .0094 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NO LOAD WITH 6.5VRMS APPLIED TO TERMINALS 3-4, MEASURE .325 VRMS 1-2, .375 VRMS 5-6 AND 1.25 VRMS 7-8

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE NOT APPLICABLE

REMARKS

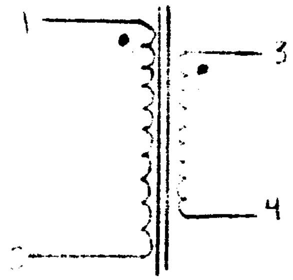
Engineer R. Seiler Date: 4/6/67

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/67

P/N 18x 716794 TYPE: 10 W. CHOKE BOOSTER USED ON: NASA STUDY

SCHEMATIC DIAGRAM	BILL OF MATERIAL AND WINDING DATA					
	Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance



Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	22	21.1'	187	1-2	.35 ±20%
3-4	597507	28	10.5'	84	3-4	.67 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

Color code and Phasing as shown

MANUFACTURING NOTES

WINDING FULL WINDING - WIND IN SEQUENCE SHOWN ABOVE

INSULATION None

CORE [illegible], MAGNETICS INC. PERMALLOY POWDER TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume .392 in cu Weight .0684 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE [illegible]

VOLTAGE APPLY 4 VRMS 20KC SINE WAVE TO 3-4 AND MEASURE 8.9 VRMS 1-2

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE 10 VRMS 20KC SINE WAVE 1-2, ≥ .00[illegible] HY @ 45MADC ; ≥ .0011 HY @ 1.2 AMP DC

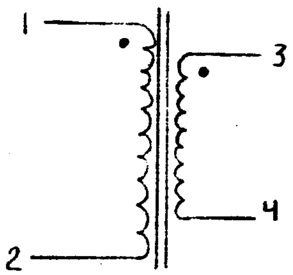
REMARKS

Engineer RScauer	Date: 4/6/67
Approval	Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/67

P/N 1Hx 716795 TYPE: 25W CHOKE - BOOSTER USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	18	15'	88	1-2	.04 ±20%
3-4	597507	28	6'	34	3-4	.04 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING FULL WINDING - WIND IN SEQUENCE SHOWN ABOVE

INSULATION NONE

CORE 55930-W4, MAGNETICS INC., PERMALLOY POWDER TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume .948 in cu Weight .1576 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE 1-2, 3-4 AND RECORD

VOLTAGE APPLY 4VRMS 30KC SINE WAVE TO 3-4 AND MEASURE 10.3VRMS 1-2

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE 10VRMS 30KC SINE WAVE 1-2; ≥.0012HY @60MADC, ≥.0006HY@ 2.6 AMP DC

REMARKS

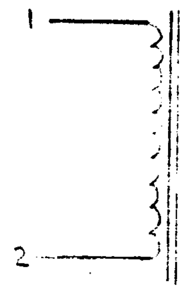
Engineer R Seaver Date: 4/6/67

Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/67

P/N 18x 716726 TYPE: 10 W. CHOKE - CHOPPER USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	22	21.1'	187	1-2	.35 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING FULL WINDING

INSULATION NONE

CORE 55-20 W4, MAGNETICS INC., PERMALLOY POWDER TOROID

BOBBIN NOT APPLICABLE

SHIELD N[illegible]

TERMINALS min. length 8 in. [illegible] MIN. LENGTH [illegible]

ASSEMBLY NOT A[illegible]

IMPREGNATION N[illegible]

OTHER- Dimensions: Length Width Height Volume .392 in cu Weight .0631 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE [illegible]

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE [illegible]

DIELECTRIC [illegible]

INDUCTANCE $\geq$.002 Hy WITH 45MA DC, $\geq$.0011 Hy WITH 1.2 AMP DC 10VRMS 30KC SINEWAVE

REMARKS

Engineer R[illegible] Date: 4/6/67

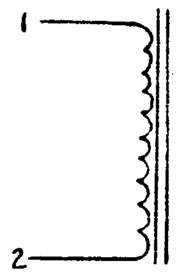
Approval Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET

DATE:

P/N 18x 716727 TYPE: 25 W. CHOKE-CHOPPER USED ON: NASA STUDY

SCHEMATIC DIAGRAM



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	15	16'	94	1-2	.10 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING Full winding

INSULATION None

CORE 55920-W4, Magnetics Inc., Permalloy [illegible]

BOBBIN Not Applicable

SHIELD Not Applicable

TERMINALS min. length 8 in. Self leads [illegible]

ASSEMBLY Not Applicable

IMPREGNATION None

OTHER- Dimensions: Length Width Height Volume .948 in³ Weight .1546 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE Measure and record

VOLTAGE Not Applicable

INSULATION RESISTANCE Not Applicable

DIELECTRIC Not Applicable

INDUCTANCE ≥ .0012 HY @ 60 MA [illegible]

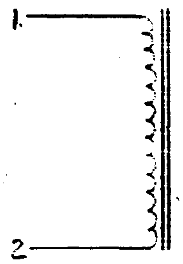
REMARKS

Engineer	Date:
Approval	Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET	DATE: 4/6/67

P/N 18x 716728 TYPE: 50 WATT CHOKE USED ON: NASA STUDY

SCHEMATIC DIAGRAM CHOPPER - BOOSTER



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	15	12.3'	65	1-2	.039 ± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING FULL WINDING

INSULATION NONE

CORE 55254-W4 MAGNETICS INC. PERMALLOY [illegible]

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS
min. length 8 in. [illegible] LEADS MIN LENGTH [illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume 2.58 [illegible] Weight .3215 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

10VRMS 30KC SINEWAVE
INDUCTANCE 2.65 mH @ .09ADC, 2.33 mH @ 4.9ADC

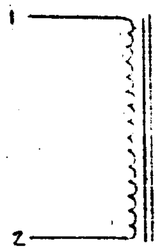
REMARKS

Engineer R. SEAVER	Date: 4/6/67
Approval	Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 4/6/[illegible]

P/N 18x 716729 | TYPE: 100N-CHO[illegible] | USED ON: [illegible]

SCHEMATIC DIAGRAM CHOPPER-BOOST[illegible] | BILL OF MATERIAL AND WINDING DATA



Color code and Phasing as shown

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistan
1-2	597527	15	11'	69	1-2	.03[illegible] ±[illegible]
						±
						±
						±
						±
						±
						±
						±
						±
						±
						±
						±
						±
						±
						±
						±

MANUFACTURING NOTES

WINDING FULL WINDING

INSULATION NONE

CORE [illegible]324-W4, MAG[illegible] INC. [illegible] T[illegible]

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS
min. length 8 in. SELF LEAD[illegible]

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER- Dimensions: Length Width Height Volume [illegible] Weight .2[illegible] lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE ALL [illegible]

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE 17VR[illegible]
2.5mh @ .09ADC, [illegible]

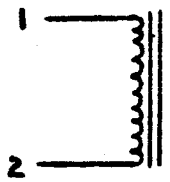
REMARKS

Engineer R. S[illegible]	Date: 4/6/67
Approval	Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 4/6/67

P/N 716796 | TYPE: FILTER CHOKE 10W. BOOSTER | USED ON: NASA STUDY

SCHEMATIC DIAGRAM INPUT-OUTPUT | BILL OF MATERIAL AND WINDING DATA



Color code and Phasing as shown

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	22	3'	22	1-2	.05 ±20%
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %
						± %

MANUFACTURING NOTES

WINDING WIND TIGHTLY AND SPREAD AROUND 360° OF CORE

INSULATION NONE

CORE 55040-M4, MAGNETICS INC., PERMALLOY POWDER TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS - MIN. LENGTH 5"

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER - Dimensions: Length | Width | Height | Volume .0491 cu in | Weight .0172 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE ≥ 15 μh WITH 1 VOLT RMS AND 2 AMPS DC

REMARKS

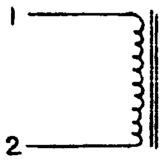
Engineer R Seaver | Date: 4/6/67

Approval | Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET | DATE: 4/6/67

P/N HS 716797 | TYPE: FILTER CHOKE 25W. BOOSTER | USED ON: NASA STUDY

SCHEMATIC DIAGRAM - INPUT - OUTPUT



Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	18	3'	22	1-2	.02 ±2

MANUFACTURING NOTES

WINDING WIND TIGHTLY AND SPREAD AROUND 360° OF CORE

INSULATION NONE

CORE 55050-W4, MAGNETICS INC., PERMALLOY POWDER TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS min. length 8 in. SELF LEADS - MIN. LENGTH 5"

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER - Dimensions: Length Width Height Volume .0962 IN CU Weight .0172 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE MEASURE AND RECORD

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE ≥ 10 µh WITH 1 VOLT RMS AND 3 AMPS DC

REMARKS

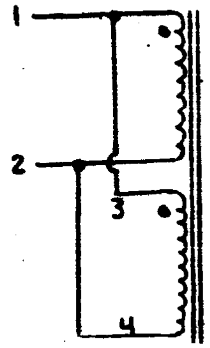
Engineer R Seaver | Date: 4/6/67

Approval | Date:

DEVELOPMENT TRANSFORMER AND INDUCTOR MANUFACTURING DATA SHEET DATE: 4/6/67

P/N [illegible] 716795 **TYPE:** FILTER CHOKE 50/100W BOOSTER **USED ON:** NASA STUDY

SCHEMATIC DIAGRAM INPUT - OUTPUT



BIFILAR WOUND

Color code and Phasing as shown

BILL OF MATERIAL AND WINDING DATA

Winding Sequence	H. S. Part No.	AWG	Approx. Length	Turns	Terminal	Approx. Resistance
1-2	597507	18	3'	22	1-2	.02 ±[illegible]
3-4	597507	18	3'	22	3-4	.02 ±[illegible]

MANUFACTURING NOTES

WINDING BIFILAR WIND AND CONNECT AS SHOWN IN SCHEMATIC

INSULATION NONE

CORE 55120-W4, MAGNETICS INC., PERMALLOY POWDER TOROID

BOBBIN NOT APPLICABLE

SHIELD NOT APPLICABLE

TERMINALS
min. length 8 in. SELF LEADS - MIN. LENGTH 5"

ASSEMBLY NOT APPLICABLE

IMPREGNATION NONE

OTHER. Dimensions: Length Width Height Volume 0.261 IN cu Weight .0444 lbs

TESTS REQUIRED

MARK WITH PART NO. AND ATTACH TAG WITH TEST RESULTS

RESISTANCE CONNECT 1-3 AND 2-4 AS SHOWN, MEASURE AND RECORD

VOLTAGE NOT APPLICABLE

INSULATION RESISTANCE NOT APPLICABLE

DIELECTRIC NOT APPLICABLE

INDUCTANCE ≥ 20 μh WITH 1 VOLT RMS AND 5 AMPS DC

REMARKS

Engineer K Se[illegible]	Date: 4/6/67
Approval	Date: